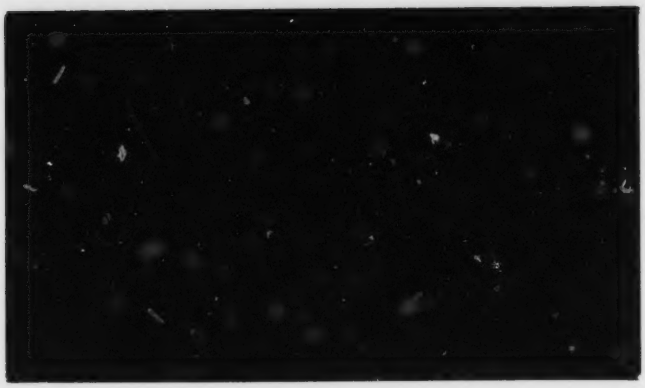

CA1
DTC800-
90
U71

41.D

THA

Thompson-Hickling Aviation Inc.

CA1
DTC800-
90
U71

450913

41.D

TP 10532E

THE USE OF COLOUR ON AIR TRAFFIC CONTROL DISPLAYS

Prepared for:

Transportation Development Centre
Policy and Coordination Group
Transport Canada
November, 1990

Prepared by:

Thompson-Hickling Aviation Inc.
255 Albert Street, Suite 601
Ottawa, Ontario
K1P 6A9

NOV 20 [illegible]
Transport Canada / [illegible]

91-03656/

The contents of this report reflect the views of Thompson-Hickling Aviation Inc., (THA) and not necessarily the official view or opinions of the
Transportation Development Centre
Transport Canada

Un sommaire de ce rapport en français précède la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 10532E	7330	

4. Title and Subtitle	5. Publication Date
The Use of Colour on Air Traffic Control Displays	November 1990
	6. Performing Organization Document No.

7. Author(s)	8. Transport Canada File No.
Peggy Campbell, Robert White, Arthur Hamilton	D1455-174-2

9. Performing Organization Name and Address	10. DSS File No.
Thompson-Hickling Aviation Inc. 255 Albert Street, Suite 601 Ottawa, ON K1P 6A9	XSD89-00001-(615)
	11. DSS or Transport Canada Contract No.
	T8200-9-9516/01-XSD

12. Sponsoring Agency Name and Address	13. Type of Publication and Period Covered
Transportation Development Centre 200 René Lévesque Boulevard, West West Tower, Suite 601 Montreal, PQ H2Z 1X4	
	14. Project Officer
	Roy S. Nishizaki

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

Careful analysis of how colour technology on high resolution displays can be applied to Air Traffic Control (ATC) applications is necessary. Designers and users must be aware of how the use of colour in this environment will affect function, comfort and performance.

The purpose of this report is to provide a review of the current relevant information as well as development guidelines for the use of colour on ATC displays.

The approach for this project consisted of developing a comparative framework which compares the functions of the video display and the attributes of using colour with each of these functions against the functional task involved in ATC. This was accomplished by the following general steps:

- Analysis of recent findings in the field of application of colour on video displays.
- Description of functional ATC tasks.
- Analysis of Canadian Automated Air Traffic System Operational Performance Requirements.
- Summary of additional applications and research in application of colour to video displays.
- Development of guidelines for use of colour on video displays, based on the comparative framework resulting from the above steps.

The results of the study are summarized in a set of guidelines which consider general controller task types, types of information displays used in ATC, related operational performance requirements, technical achievability of colour recommendations and colour-use characteristics.

17. Key Words	18. Distribution Statement
Air Traffic Control (ATC), ATC Tasks, Terminal Display, Colour Display, Video Display Terminal (VDT)	Limited number of copies available from the Transportation Development Centre on request.

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	XX,70	—

4378

Transports Canada / Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP 10532E	7330	

4. Titre et sous-titre

The Use of Colour on Air Traffic Control Displays

5. Date de la publication

novembre 1990

6. N° du document de l'organisme exécutant

7. Auteur(s)

Peggy Campbell, Robert White, Arthur Hamilton

8. N° de dossier — Transports Canada

D1455-174-2

9. Nom et adresse de l'organisme exécutant

Thompson-Hickling Aviation Inc.
255 Albert Street, Suite 601
Ottawa (Ontario)
K1P 6A9

10. N° de dossier — ASC

XSD89-00001-(615)

11. N° de contrat — ASC ou Transports Canada

T8200-9-9516/01-XSD

12. Nom et adresse de l'organisme parrain

Centre de développement des transports
200 ouest, boul. René Lévesque
Tour ouest, suite 601
Montréal, (Québec)
H2Z 1X4

13. Genre de publication et période visée

14. Agent de projet

Roy S. Nishizaki

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)

16. Résumé

Il est nécessaire de procéder à une analyse approfondie des méthodes d'application ATC (contrôle de la circulation aérienne) (ATC) de technologie de la couleur relativement aux affichages haute définition. Les concepteurs et les utilisateurs doivent connaître l'impact que peut avoir l'utilisation de la couleur dans cet environnement, particulièrement en termes de fonction, commodité et rendement.

Ce rapport a pour objet de présenter une revue de l'information courante pertinente et d'élaborer des lignes directrices relatives à l'utilisation de la couleur pour les affichages ATC.

L'approche adoptée pour ce projet consiste en l'élaboration d'un cadre comparatif des fonctions de l'affichage vidéo et des caractéristiques d'utilisation de la couleur relativement à chacune de ces fonctions avec le rôle fonctionnel ATC. Pour ce faire, on a procédé à l'exécution des étapes suivantes:

- Analyse des conclusions récentes dans le domaine d'application de la couleur pour les affichages vidéo.
- Description du rôle fonctionnel ATC.
- Analyse des exigences opérationnelles de performance CAATS (Automatisation du système canadien de la circulation aérienne).
- Résumé des applications additionnelles et de la recherche connexe en matière de couleur pour l'affichage vidéo.
- L'élaboration de lignes directrices pour l'utilisation de la couleur pour l'affichage vidéo, le tout basé sur le cadre comparatif découlant des étapes décrites ci-haut.

Les résultats de l'étude se résument sommairement dans un ensemble de lignes directrices traitant généralement des types d'obligations du contrôleur, des types d'affichage d'information utilisés par l'ATC, des exigences connexes de performance opérationnelle, et de la possibilité technique de mise en oeuvre des recommandations portant sur la couleur et sur les caractéristiques de l'utilisation de la couleur.

17. Mots clés	18. Diffusion
Contrôle de la circulation aérienne (ATC), fonctions ATC, affichage terminal, affichage couleur, terminal d'affichage vidéo (TAV)	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	XX,70	—

CDT/TDC 79-005
Rev 88

Canada

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of the following Transport Canada personnel in the preparation of this report:

Robert Fullarton
Al Hunter
Richard Osman
Rolf Stefani

THA PROJECT TEAM

Peggy Campbell
Arthur Hamilton
Richard Mogford
Ed Montgomery
Brian Tansley
Robert White
James Etgen

The TDC Project Officer was Roy S. Nishizaki

SUMMARY

Driven by ever-increasing traffic density, and rising labour and operational costs, the range and the scope of air traffic control tasks performed by a single individual have been expanded. New technology has been sought to assist air traffic controllers in coping with their increased and altered workloads. It is in this context that the advantages and disadvantages of the use of colour on Air Traffic Control (ATC) displays must be evaluated; an important goal in the design/development of improved ATC workstations being to optimize controller work performance, while minimizing controller fatigue and work-related stress.

This study considers how the use of colour as a design element in ATC displays might affect the achievement of this goal either positively or negatively. The study makes detailed reference to research already done on the role of colour in information displays, to the well-documented characteristics of human colour-vision, and to the various tasks of the air traffic controller. It further discusses the potential negative impact of variation in colour vision capabilities among the ATC personnel, as well as variations in the stability and colour calibration of cathode-ray tube (CRT) display monitors.

The scope of the project relates to the use of colour on ATC displays, through consideration of a number of associated areas such as characteristics of human vision, available display technologies and the nature of ATC tasks.

The report describes the information sources used, provides a discussion of the issues involved relative to the use of colour on video displays (including display technology, human vision, visual function, and ergonomic considerations), describes ATC tasks (touching upon information displays, and Canadian Automated Air Traffic System (CAATS) operational performance requirements), provides guidelines for use of colour in the ATC environment, and presents conclusions and recommendations.

In order to obtain the required general and scientific information, national and international literature searches were carried out. In addition, consultations took place with experts and researchers in the fields of colour on video displays and of ATC display design. The information obtained, particularly that related to the experience gained by the United States Federal Aviation Administration (FAA) and Department Of Defense (DOD), was combined by the Thompson-Hickling Aviation (THA) team of experts and adapted to the subject under consideration to ensure the development of a comprehensive product adaptable to Canadian needs. It is of interest to note that the FAA is currently developing ATC displays using colours which have largely been decided upon through collaboration with its prime contractor, International Business Machines (IBM). Also, the DOD is presently engaged in a study of human factors in automated ATC systems.

Recognizing that the role of colour as a controller aid is not yet well understood, some researchers question the usefulness of colour in ATC displays, while others warn of possible detrimental effects of colour coding on ATC performance. Notwithstanding these reservations, it becomes more and more evident that people regard colour displays as beneficial. Also, the technology associated with colour display development is gaining a stronghold. Therefore, it appears most desirable that, in the ATC environment, the technology of colour display and colour coding be developed and deployed to the advantage of the controller and of the ATC system as a whole.

The report presents a detailed analysis of the many factors associated with the application of colour to functional display screens; the intent being to discuss the characteristics of colour on displays and the impact of colour in ATC tasks, without passing any judgement on whether colour should or should not be used on ATC displays. The analysis, done in parallel with a description of the many facets of the role of the controller (with some emphasis placed on the mental processes involved in the execution of tasks and subtasks), provides a basis for the development of guidelines for the use of colour in the design of ATC displays. These guidelines touch upon:

a. design considerations;

b. number of colours that could apply;

c. luminance and brightness of displays;

d. contrast and legibility;

e. control of brightness/contrast;

f. symbol size;

g. functional uses for colour; and

h. general advantages and disadvantages of colour coding.

As a general conclusion, the report acknowledges that controllers seem to prefer colour displays, a fact which should constitute a challenge for the design of displays capable of ensuring the introduction of colour in such a manner that the performance of the controllers will not be impaired. It is recommended that further investigation be carried out to determine:

a. The effects of colour use on controller task performance, as opposed to other coding methods.

b. The use of large screen displays and their effect on controller performance.

c. The amount of visual fatigue resulting from prolonged use of large screen displays using colour and high information density.

d. The best use of redundant (monochromatic) coding in addition to colour coding on ATC displays.

e. The stability and life expectancy of large screen colour CRTs and the potential effects of display inaccuracies on controllers.

f. The colour vision characteristics of the Canadian ATC population and the implications for colour use.

SOMMAIRE

L'accroissement constant de la circulation aérienne et l'augmentation des coûts de main-d'oeuvre et d'exploitation ont amené un élargissement du domaine et de la portée des fonctions du contrôle de la circulation aérienne (ATC) exécutées par un seul individu. On tend vers l'application de techniques de pointe pour assister les contrôleurs de la circulation aérienne à assumer efficacement des charges de travail accrues et modifiées. C'est dans ce contexte que les avantages et les désavantages reliés à l'utilisation de la couleur dans les affichages ATC doivent être évalués; un des objectifs principaux de conception et de développement de postes de travail ATC améliorés étant de maximiser le rendement opérationnel du contrôleur, tout en minimisant les effets de la fatigue et du stress.

Cette étude cherche à déterminer comment l'utilisation de la couleur, comme élément de base dans les affichages ATC, pourrait influer de façon positive ou négative sur la réalisation de cet objectif. Elle réfère abondamment à la recherche déjà réalisée sur le rôle de la couleur dans l'affichage de l'information, aux particularités bien documentées de la vision humaine de la couleur, et aux diverses fonctions du contrôleur de la circulation aérienne. De plus, elle porte sur l'impact négatif possible de variation des aptitudes de vision de la couleur du personnel ATC, et des variations dans la stabilité et l'ajustement de la couleur du moniteur d'affichage à tube cathodique (TRC).

Le projet porte sur l'utilisation de la couleur dans l'affichage ATC considérant, pour ce faire, un certain nombre de domaines associés comme les particularités de la vision humaine, les techniques d'affichage disponibles, et la nature des fonctions ATC.

Le rapport indique les sources d'information utilisées, discute des questions relatives à l'utilisation de la couleur dans l'affichage vidéo (y compris les techniques d'affichage, la vision humaine, la fonction visuelle, et les considérations d'ordre ergonomique), définit les fonctions ATC (faisant état des affichages d'information et des exigences de performance opérationnelle de l'Automatisation du système canadien de la circulation aérienne (CAATS)), fournit des lignes directrices sur l'utilisation de la couleur dans l'environnement ATC, et présente des conclusions et des recommandations.

Pour obtenir l'information générale et scientifique, on a procédé à une recherche nationale et internationale. De plus, on a consulté des experts et des chercheurs dans les domaines de la couleur d'affichage vidéo et de la conception de l'affichage ATC. L'information ainsi obtenue, particulièrement celle reliée à l'expérience acquise par la Federal Aviation Administration (FAA) et le Department of Defense (DOD) des Etats-Unis, a été colligée par l'équipe d'experts de Thompson-Hickling Aviation (THA) et adaptée au sujet à l'étude pour assurer le développement d'un produit détaillé et complet, susceptible de pouvoir satisfaire aux exigences canadiennes. Il est intéressant de noter que la FAA est à développer des affichages ATC, utilisant des couleurs déjà déterminées, ou presque, de concert avec le contractant principal (International Business Machines (IBM)), et que le DOD est à effectuer une étude des facteurs humains reliés à l'automatisation des systèmes ATC.

Conscients du fait que le rôle de la couleur comme outil de travail susceptible d'aider le contrôleur n'est pas encore perçu de façon satisfaisante, certains chercheurs s'interrogent sur l'utilité de la couleur dans l'affichage ATC, tandis que d'autres adressent une mise en garde sur la possibilité d'effets nuisibles sur le rendement effectif ATC pouvant résulter du codage de la couleur. Malgré ces observations, il apparait de plus en plus évident que les gens, en général, perçoivent bien le rôle

bénéfique que l'affichage couleur semble jouer. Aussi, la technologie associée au développement de l'affichage couleur se fait de plus en plus présente. Par conséquent, il apparait très désirable que les techniques d'affichage et de codage couleur, dans l'environnement ATC, soient développées et appliquées ausi bien à l'avantage du contrôleur que du système ATC dans son ensemble.

Le rapport présente une analyse détaillée de plusieurs facteurs associés à l'application de la couleur sur les écrans d'affichage fonctionnels; le but étant de discuter des particularités de la couleur sur les affichages et de l'impact de la couleur sur les fonctions ATC, sans pour autant porter jugement sur le besoin, ou non, d'utiliser la couleur dans l'affichage ATC. L'analyse, effectuée en parallèle avec une description des divers aspects du rôle du contrôleur (mettant l'accent sur le processus mental relié à l'exécution des fonctions et sous-fonctions), fournit une base au développement de lignes directrices sur l'utilisation de la couleur dans la conception des affichages ATC. Ces lignes directrices traitent:

a. de considérations d'ordre conceptuel,

b. du nombre de couleurs pouvant s'appliquer,

c. de la luminance et de la luminosité des affichages,

d. du contraste et de la lisibilité,

e. du contrôle de la luminosité/contraste,

f. de la grosseur du symbole;

g. de l'utilisation fonctionnelle de la couleur; et

h. des avantages et des désavantages généraux du codage couleur.

Comme conclusion générale, le rapport fait état du fait que les contrôleurs semblent préférer l'affichage couleur; ce qui devrait constituer un défi au niveau de la conception d'affichages capables d'assurer l'avènement de la couleur de telle manière que le rendement effectif des contrôleurs n'en sera pas négativement affecté. Il est donc recommandé qu'une plus ample recherche soit effectuée pour déterminer:

a. les effets de l'utilisation de la couleur sur le rendement effectif d'exécution des fonctions du contrôleur, par opposition aux autres méthodes de codage;

b. l'utilisation d'affichage sur grands écrans et leur effet sur le rendement effectif du contrôleur;

c. le degré de fatigue visuelle résultant de l'utilisation prolongée d'affichage sur grands écrans, utilisant la couleur et une haute densité d'information;

d. la meilleure utilisation de codage redondant (monochrome) en combinaison avec le codage de la couleur sur l'affichange ATC;

e. la stabilité et l'espérance de vie des tubes cathodiques (TRC) des grands écrans "couleur", et les effets potentiels des inexactitudes d'affichage sur les contrôleurs;

f. les particularités de vision de la population ATC canadienne et les implications connexes de l'utilisation de la couleur.

TABLE OF CONTENTS

Page

SUMMARY vii

SOMMAIRE ix

1.0 INTRODUCTION 1
- 1.1 Scope 1
- 1.2 Objectives 1
- 1.3 Plan of Report 1

2.0 INFORMATION SOURCES 3
- 2.1 Literature Searches 3
- 2.2 Experts and Researchers 3

3.0 ISSUES IN COLOUR USE 9
- 3.1 General Considerations 9
  - 3.1.1 Dissociation from Other Properties of Objects 9
  - 3.1.2 Colour Information Processing 10
  - 3.1.3 Colour Coding 10
  - 3.1.4 Large Format Displays 11
- 3.2 Display Technology 12
  - 3.2.1 Cathode Ray Tubes (CRTs) 12
  - 3.2.2 Other Display Technologies 14
  - 3.2.3 Hardware Issues 15
- 3.3 Human Vision 19
  - 3.3.1 Function of the Eye 19
  - 3.3.2 Spatial Vision 20
  - 3.3.3 Temporal Vision 21
  - 3.3.4 Colour Vision 21
  - 3.3.5 User Population 26
- 3.4 Visual Function in ATC 27
  - 3.4.1 Types of Stimuli 28
  - 3.4.2 Colour Perception 28
  - 3.4.3 Visual Tasks of Air Traffic Control 29
- 3.5 Ergonomic Considerations 34
  - 3.5.1 Stimulus to Accommodation 34
  - 3.5.2 Display Polarity 34
  - 3.5.3 Lighting 35
  - 3.5.4 Glare 35
  - 3.5.5 Large Screen Viewing Area 36
  - 3.5.6 Visually-Derived Fatigue and Prolonged Viewing of Colour Displays 36
  - 3.5.7 Potential Colour Coding Problems 37

TABLE OF CONTENTS (Continued)

4.0 ATC TASKS AND DISPLAYS 39
4.1 Role of the Controller 39
4.2 ATC Task Descriptions 40
4.3 Presentation of ATC Information 40
4.3.1 Messages and Command Feedback 41
4.3.2 Tabular Displays 42
4.3.3 Situation and Graphics Displays 43
4.3.4 Windowing 43
4.4 CAATS Operational Performance Requirements 44
4.4.1 Alphanumerics 44
4.4.2 Graphics 46
4.4.3 Logical Display Layout 48

5.0 GUIDELINES FOR USE OF COLOUR 49
5.1 Application of Colour 49
5.1.1 Design Considerations 49
5.1.2 Functional Uses for Colour 52
5.2 Advantages and Disadvantages of Colour Coding 53
5.3 Guidelines 56

6.0 CONCLUSIONS AND RECOMMENDATIONS 61

REFERENCES 63

APPENDIX A: EXPERTS AND RESEARCHERS A-1

APPENDIX B: CHROMATICITY DIAGRAM B-1

APPENDIX C: TASK DECOMPOSITION C-1

APPENDIX D: EXTRACTED FROM CAATS OPERATIONAL PERFORMANCE REQUIREMENTS, TRANSPORT CANADA PUBLICATION TP 9166E D-1

LIST OF FIGURES

FIGURE 1: Examples of Spectral Energy Distributions (Kinney, 1978) 22
FIGURE 2: Retinal Colour Sensitivity Areas (Woodson, 1981) 26
FIGURE 3: CIE 1976 Chromaticity (SAE, 1989) B-3

LIST OF TABLES

TABLE 1: Colour Use Guidelines 57
TABLE 2: ATC Task Requirements Matrix C-7

ACRONYM LIST

AAS:	Advanced Automation System
ACID:	Aircraft Identification
APREQ:	Approval Request
ARU:	Altitude Reservation Unit
ATC:	Air Traffic Control
CAATS:	Canadian Automated Air Traffic System
CCWS:	Common Controller Workstation
CIE:	Commission Internationale de l'Eclairage
CISTI:	Canada Institute for Scientific and Technical Information
CRT:	Cathode Ray Tube
CTDPS:	Control Tower Data Processing System
CTWS:	Control Tower Workstation
DAC:	Digital to Analog Converter
DOD:	Department of Defence (U.S.)
EL:	Electroluminescent
FAA:	Federal Aviation Administration (U.S.)
FDE:	Flight Data Entry
FDPS:	Flight Data Processing System
IES:	Illumination Engineering Society
LCD:	Liquid Crystal Display
LCS:	Liquid Crystal Shutter
LED:	Light Emitting Diode

MMIP:	Man-Machine Interface Program
OPR:	Operational Performance Requirements (for CAATS)
PED:	Position Entry Device
RGB:	Red-Green-Blue
SAE:	Society of Automotive Engineers
SED:	Spectral Energy Distribution
VFD:	Vacuum Fluorescent Display

GLOSSARY

Brightness: The perception of the intensity of light reflected by an object of emitted by a source of light. It is the perceptual correlate of luminance and, hence, can only be measured via human observations and not via instrumentation.

Chromaticity: Chromaticity of an object approximately corresponds to its colour in ordinary language (although the relationship may vary with varying luminosity. Often used to denote a combination of hue and saturation.

Chromaticity Coordinates:

The chromaticity coordinates for a colour are the ratios of each tristimulus value of the colour with their sum in the CIE system. The tristimulus values (X, Y & Z) are based on the amounts of each of three reference lights needed to make an additive colour mix that will match the colour in question. Since the sum of the chromaticity coordinates always equals 1, only two coordinates need be given to describe a colour. This serves to completely describe two psychophysical qualities of every colour: dominant wavelength and excitation purity. These correspond to the perceptual qualities of hue and saturation. A third term, the Y tristimulus is the luminance of the colour.

Diopter: The unit for measuring the refractive power of a lens, expressed as the reciprocal of its focal length in meters.

Dominant Wavelength:

Dominant wavelength correlates with the hue of a colour. It is the spectrum colour one would mix with the reference white in order to make a colour match.

Hue: The quality of light that is characterized by the words green, red, blue, yellow, etc. Hue is generally determined by the dominant wavelength of the light observed, and is independent of both saturation and brightness.

Luminance: The amount of light emitted, transmitted or reflected from a display, light source, or other object. It can be measured by instrumentation. The SI units are candelas per square meter (nits), abbreviated n/t while the older British units are footlamberts, abbreviated as fL. One footlambert is equivalent to 3.425 nits. Luminance is a psychophysical measure since it takes into account both the physical amount of light, known as radiance, and the response of the human eye to light.

Luminosity (brightness):

The attribute of visual sensation according to which an area appears to admit more or less light.

Photopic: Lighting conditions that permit colour discrimination.

Saturation: The perceptual attribute of excitation purity. It is the deviation of a colour from white. Monochromatic colours (spectrum colours) are by definition highly saturated. Highly desaturated colours appear very pale, that is whitish or grayish.

Scotopic: Low illumination that does not permit colour discrimination, but permits monochromatic (or rod) vision.

Spectrum Colour:

Spectrum colours are those colours that are produced by passing white light through a prism and appear on the boundaries of the CIE Chromaticity Diagrams.

1.0 INTRODUCTION

The emphasis upon increased operational efficiency in air traffic control, necessitated by increased air traffic density and by rising labour and operational costs, has motivated the design of new ATC systems in which fewer people handle a greater number of aircraft. In Canada, the range and the scope of ATC tasks performed by a single individual have been expanded. New technology has been sought to assist Air Traffic Controllers in coping with their increased and altered workloads. In this context the advantages and disadvantages of the use of colour on ATC displays must be evaluated.

An important design goal in the development of any improved ATC workstation should be the optimization of controller work performance. Where possible, design effort should be expended to effect changes/improvements that serve to minimize controller fatigue and work-related stress.

This document considers how the use of colour as a design element in ATC displays might impact upon the achievement of this goal, either positively or negatively (or both). In order that this be done, an understanding of the body of research on the role of colour in information displays, the characteristics of human colour vision, and the various subtasks of the air traffic controller is necessary. There is also discussion of the potential negative impact of variations in colour vision capabilities among the ATC personnel and variations in the stability and colour calibration of CRT display monitors.

1.1 Scope

The scope of the project relates to the use of colour on air traffic control displays. This report considers a number of associated areas, including characteristics of human vision, available display technologies and the nature of ATC tasks.

1.2 Objectives

The objectives of this study are:

a. To collect and analyze information concerning the current use of colour in ATC;

b. To provide background information for the use of colour on information displays in ATC, considering the characteristics of users, displays and working environments, and

c. To provide guidelines for the application of colour on ATC information displays.

1.3 Plan of Report

This report is presented in six sections. **Section 1** provides the introduction to the report. **Section 2** briefly describes the information sources used in preparing the report. **Section 3** provides a discussion of the issues involved in colour use on video displays, including display technology, human vision, visual function and ergonomic considerations. **Section 4** describes ATC tasks, information displays and the CAATS operational performance requirements. **Section 5** provides guidelines for use of colour in the ATC environment. **Section 6** presents the conclusions and recommendations of the report.

2.0 INFORMATION SOURCES

2.1 Literature Searches

To obtain the reference literature reviewed and consulted for this report, several searches were made. Much of the information was immediately available from the libraries of Thompson-Hickling Aviation Inc., Jerry Thompson & Associates Inc. and HICKLING. Further searches of CISTI using the DOBIS system were made. A search of the FAA Technical Center Library was also made. Literature that was used as source material is included in the References section.

2.2 Experts and Researchers

In researching this report, a number of informal contacts were made with experts and researchers in the fields of colour on video displays and ATC display design. A list of these contacts is provided in Appendix A. A summary of the results of these conversations is provided below.

a. Hugh David, Ph.D.
Eurocontrol Research Centre
Bretigny-sur-Orge
France

Dr. David has been experimenting with the SONY 20 X 20 in. display. He has voiced some concerns about the reliability of the SONY CRT and whether it will be reliable under operational conditions.

At Eurocontrol, Dr. David has completed a number of studies (from 1981 through 1989) on the use of colour in air traffic control. Recent work has included the evaluation of an electronic flight strip system. A monochrome display format was compared with two different strategies for colour coding (action-oriented vs. direction-oriented). It was found that the monochrome labelling was successful but that the colour displays each had some disadvantages. A compromise coding, combining the better features of both colour formats, was developed and evaluated.

b. Jim Guttman, Ph.D.
Federal Systems Division
IBM Corp.
Rockville, U.S.A.

Dr. Guttman was involved in the IBM proposal for the Federal Aviation Administration's (FAA) new air traffic control system. When asked about the work which led up to the recommendations for colour he said that no early empirical research had been completed. A review of the human factors literature and consultations with operational experts led to an acceptable preliminary proposal for the use of colour and this was accepted by the FAA. Further testing of the colour philosophy is planned as system development proceeds. However, Dr. Guttman noted that testing the actual effects of colour in the context of the entire system would be difficult. He recommended reading Hopkin (1980) and Cahill and Carter (1976) for insights on his approach to the study and use of colour in the IBM system.

c. Mr. Chris Metcalfe
Head of RD1
Civil Aviation Authority
London, UK

Mr. Metcalfe has just let a contract to the Royal College of Art for a two year study on the use of colour in ATC. The first year will of work will focus on a literature survey and the second year will address the use of colour for both coding and decluttering. He expressed concerns regarding the technical performance of the SONY monitor which is intended for use in the U.S. and Canadian ATC systems. Mr. Metcalfe's main criticisms were that screen luminance is too low (necessitating a low level of facility lighting), convergence specifications are inadequate, flicker in filled screen areas is high because of the phosphor used, and that in reality only 1606 X 1606 (as opposed to the advertised 2016 X 2016) pixel resolution is available.

d. Mr. Frank Yohe
Federal Aviation Administration
Washington, U.S.A

The FAA is currently developing ATC displays for their Advanced Automation System (AAS). The application of colour on these displays has been largely decided. The FAA's philosophy of colour use is to draw attention to data or situations requiring action. This implies the use of colour to indicate the state of information rather than for grouping purposes. The FAA intends to use seven colours on a black background. The chosen colours and their meanings are as follows:

Green: The nominal colour, used to display the majority of information; indicates normal conditions with no need for action.

White: Used to indicate that new information is being displayed; presented in automatic mode; controller acknowledgement is not required.

Yellow: Used to indicate that controller action or acknowledgement is required.

Red: Used exclusively for emergency situations; immediate controller action is required.

Cyan and
Magenta: Used to portray operational information such as direction of flight or arrivals/departures.

Blue: Reserved as a distinguishable, non-interfering colour; used with differing shades to indicate intensity of weather conditions.

e. Capt. Guy St. Sauveur
Hanscom AFB
U.S.A.

The U.S. Air Force has recently initiated a study on human factors in automated ATC systems as a joint effort between Department of Defense (DOD) and the FAA. This work will take into consideration systems in Canada, the UK, and the Netherlands and will include research on the use of colour.

f. Mr. Roy Kaufmann
Ms. Sharon McFadden
Defence and Civil Institute of Environmental Medicine (DCIEM)
Toronto, Canada

A number of the human factors researchers at DCIEM have been investigating the use of colour on displays in military settings (but not necessarily in air traffic control). Roy Kaufmann and Sharon McFadden completed a paper summarizing the knowledge relevant to the use of colour on electronic displays in 1989. They included in their report a list of 13 guidelines for the application of colour. In another study, Roy Kaufmann discussed colour on electronic charts for the Canadian Hydrographic Service and outlined 10 recommendations.

In a much larger project, Litton Systems Canada Ltd. completed a two stage study for DCIEM on the effects on human performance of mono- and multi-chromatic displays (1984 to 1988). The general project goal was to formulate guidelines for defining the chromaticity of colours for electronic displays which would produce the least eye discomfort. Phase I was a literature review and knowledge assessment. Phase II was completed by two researchers, J. Lovasik, Ph.D. (U. of Waterloo) and M. Matthews, Ph.D. (U. of Guelph). The main conclusion of this work (which combined electrophysiological, psychophysical, and behavioural measures) was that subjective visual fatigue resulting from the use of a colour display was not related to the display colours being used. Target colour also had no direct influence on operator performance. It was recommended that it was safe to implement colour on operational displays.

g. Ms. Barbara J. Ford
Defence Research Establishment
Ottawa, Canada

Ms. Ford conducted research project on the use of colour in a general area air traffic control simulation in 1983. She commented that advances in raster display technology have overcome many of the limitations on the display of colour which were present at the time of her study. Three colours, red, yellow, and green were used in this project. Red was employed for alerting the user of problems (such as aircraft conflicts), yellow was considered as a lower urgency alerting colour, and green was used for the background.

h. Dr. Ed Buckley
Federal Aviation Administration Technical Centre
Atlantic City, U.S.A.

Dr. Buckley has not been involved in much work on colour at the technical centre. However, he suggested a contact with the FAA library. There a literature search for previous projects on the use of colour in ATC was conducted. A review of the references indicates that a number of studies on colour have been completed. However, there has not been a consensus on whether or not the application of colour in ATC systems provides very many advantages over monochromatic coding.

i. Hughes Aircraft Corporation
Ground Systems Group
Fullerton, CA 92634

Information regarding Hughes Aircraft (who competed with IBM for the FAA Advanced Automation System contract and for the Canadian CAATS contract) is available through Mr. Hubert Gervais at the CAATS office and will not be reported here.

j. Russ Benel, Ph.D.
MITRE Corp.
Civil Systems Division
McLean, VA
U.S.A.

Dr. Benel (now with MITRE) was the manager for human factors engineering during the development of IBM's version of the AAS for the FAA competition. He also indicated that the work on the use of colour in IBM made use of available research and guidelines and did not involve any empirical research. The resulting application of colour on the IBM system was well received by the user evaluation group and will be tested as system development continues. He commented that map lines are green in the AAS because of the lack of screen convergence problems with this colour and because there are few problems with the perception of green. Colour assignments were based on intuitive and common sense as well as cultural stereotypes.

k. Maria Picardi
MIT Lincoln Laboratories
Lexington, MA

Maria Picardi communicated that, in association with the FAA, a human factors committee has been developed for the study of issues in ATC. They are currently in the planning stage. Several research projects are being considered, some of which will include colour use on ATC displays. She is involved in studies concerning automation concepts for air traffic control (for the FAA).

3.0 ISSUES IN COLOUR USE

The application of colour to functional display screens such as those that may be used in the ATC environment can be a contentious issue. Some reviewers feel that the potential gains from colour are currently conjectural and that the associated costs and risks outweigh any presumed advantages of its use. (Paul, 1986) Most sources recommend conservative use of colour, taking the attitude that adding colour to ATC displays might be detrimental to controller performance unless carefully designed, while "there are no technical grounds for suspecting that colour will not benefit controller performance." (Kinney, 1978)

This section does not judge whether colour should or should not be used on ATC displays. It does, however, discuss the characteristics of colour on displays and the impact of colour in ATC tasks. The information in this section serves as a basis for developing guidelines for colour use in Section 5.

3.1 General Considerations

"Colour continues to be universally welcomed, apparently whether it is helpful or not."
(V. D. Hopkin, 1989)

Depending upon which reference you read, the use of colour in ATC displays can be either the solution to the problem of how to increase the effective bandwidth of an ATC display or yet another example of a solution in search of a problem. The role of colour as a controller aid is not yet well understood. Indeed, some researchers question the usefulness of colour in ATC displays at all, while others (albeit fewer) warn of the possible detrimental effects of colour coding on ATC performance. These concerns notwithstanding, people widely regard colour displays as beneficial and based upon sales, it would appear that colour display technology is gaining a stronghold. It is desirable that the technology of colour displays and colour coding be deployed to the advantage of the controller and to the ATC system as a whole. Failing this, it is important that colour coding be used in ways that are not harmful to the effectiveness of the system.

The fact that most people have colour vision suggests its value to us. We use the information obtained from the colour of natural objects in a wide variety of ways: for perceptual grouping of similarly shaped objects in different parts of the visual field, for detecting objects in complex natural scenes, for determining whether food is suitable for eating, for assessing the health of individuals through the colour of their skin, etc. These uses of colour evolved along with the sensory system for detecting colour and differences over millions of years.

3.1.1 Dissociation from Other Properties of Objects

Colour can be dissociated from the other properties of objects. In the natural world, colour is but one property of the objects around us. Everything that we can see can be verbally described in terms of its visual properties. We are conscious of these properties and can communicate our awareness of them to others as a list of attributes of which colour is but one part. Only recently has man come to use colour as a solitary information source--one that can be dissociated from the other attributes of visible things.

While most of us are readily able to see colour and use it, though it be dissociated from other perceptual descriptors in this way, the implications for how we represent such information in the brain and how we efficiently link it to other types of information is only beginning to be understood.

Given that colour can be dissociated from other properties, the relationship between colour and other properties can be made to be completely arbitrary. This, at once, makes system design using arbitrary colour conventions both easier for the designer and harder for the user, since there is no unique mapping of colour to meaning.

3.1.2 Colour Information Processing

The processing of colour coded information appears to be special in that it involves some "preattentive" perceptual processes. The colour attributes of objects in the visual world seem to be extracted by the visual system of humans at a very early stage--perhaps one that does not require the information processing resources normally associated with the execution of various other visually guided tasks. This makes the potential for colour coding important for the controller workstation, as attention is one of the attributes of the performance capacity of the controller that is often in short supply. In this way colour coding might assist the controller in searching, identifying and locating objects or areas of the screen devoted to a single logical display.

The use of other visual attributes can and have been dissociated from the other attributes of objects in the natural world with which they have been historically associated. The arbitrary assignment of dissociated attributes, such as shape, for example, is the basis of a wide variety of communication systems, including all alphabets.

Colours have been used in signal alphabets in this manner in a variety of applications. Examples include the coding of resistance values on resistors, the coding of information (such as altitude) on maps, the coding of photographic density (pseudocolour mapping) in digital image processing applications and the coding of road intersection control through the use of the well-known red, amber and green traffic light signal alphabet.

3.1.3 Colour Coding

What effect does the dissociation of colour from the attributes of objects have upon its utility as a dimension for coding information? The answer lies in the fact that the coding procedure in which different colours are associated with different meanings is, for the most part, arbitrary. Thus, it must be learned. Therefore colour coding should be regarded as nothing special. It is simply the assignment of arbitrary perceptually discriminable states to arbitrary meanings so as to make it possible to communicate those meanings to people from machinery. The success of colour in the examples above has been due to its use in ways that make ergonomic sense.

Introducing colour into the ATC workstation in ways that make ergonomic sense is not simple. This is because of the many interacting and potentially interfering subtasks and the many sources of information that the controller must attend during the performance of his/her work--all of which may potentially benefit from the use of colour.

Because of its properties, colour has the potential for being effective in a number of ways in the ATC workstation display. For example, colour may be useful for delimiting logical displays from one another, for colouring maps and other graphics; for highlighting (i.e., making it possible to visually discriminate a group of symbols that appear the same by colouring them different colours) or clustering (i.e., making it possible to visually group a set of symbols together from all over the screen because they all have the same colour).

While the potential for advantageous use of colour is great, there is a surprising lack of unanimity in the scientific and technical literature with respect to both whether the use of colour is a good idea and, if it is, how it should be implemented.

3.1.4 Large Format Displays

Improvements in electronic data processing have made it possible to consolidate many of the information sources that the controller uses. The advent of high-resolution, large format visual display monitors and digital graphics technology now make it feasible to design ATC workstations where most, if not all, of the necessary visual information needed by the controller is available within a central field of view.

Centralizing visual ATC information onto one or more large format digital graphics display monitors offers a number of potential advantages for optimizing work performance. First, it reduces the amount of visual search time and effort required to obtain specific information available off the visual axis (thus effectively increasing the information acquisition rate of the controller). As a consequence of this, it also offers the promise of reduced operator fatigue by minimizing the number and extent of head movements required during ATC procedures.

Second, it renders all information at the same effective distance away from the head, reducing or eliminating the requirement to change the accommodative state of the eye when turning to look at another display that may be either closer or farther away.

Third, it makes possible for the first time a means whereby the controller can make dynamic spatial associations among different types of data. Because of the size of the displays, ever larger amounts of data can be presented simultaneously to the controller's field of view. Modern software tools can provide pointers among several databases that permit them to be linked together under system or user command structures. However, the problem of visually representing these associations remains. In most colour coding schemes related data are coded with the same colour. Properly designed colour coding schemes can provide visual association cues that assist the controller in searching for and processing related information from disparate databases. Appropriate colour coding schemes also provide cues for searching for related information in logical displays (windows) that may have yet to be invoked by the controller in a given situation.

Colour coding has some advantages over other schemes. For example, contrast highlighting or contrast inversion of symbols on a cathode ray tube (CRT) display can interfere with the perception of the shape of symbols. (Shape alterations can be digitally corrected but this can require expensive computing resources.) Colour coding of arbitrarily related symbols, areas, flight paths, etc. can be achieved simply and efficiently. This advantage may be completely offset, however, by the difficulty

in learning the necessary associations between arbitrary colours and arbitrary system states to which they are mapped.

One of the observable effects of centralization of ATC information on larger, digital graphics displays will be the spatial compression of alphanumeric and graphical information; a trend toward more, smaller alphanumeric characters within the boundaries of the display screen. While decreasing acquisition time because of the decreased need for head-on-neck movements, as noted above, increased symbol/character density may lead to a greater visual search task load within the central field of vision. While it is difficult to estimate the tradeoff, it is clear that at least some additional attentional effort may have to be expended to selectively search for information in such a display.

Colour may profitably be used as an aid in the detection and identification of specific information in high density centralized arrays such as described above, either by providing a perceptually salient attribute to search for, or by highlighting specific areas such as various data windows.

3.2 Display Technology

Computers produce their digital information in the form of electrical impulses, and a computer display must translate these impulses into two-dimensional monochromatic or colour patterns. Patterns on a colour display are obtained by varying the intensity of the primary colour phosphors making up the pixels over the display matrix. The three primary colours red, green and blue are usually used, so that points in the matrix are often referred to as trixels. What makes each video display technology different is the physical and chemical process by which each pixel is activated or illuminated.

There are several technologies for displaying computer information currently available. These include the Cathode Ray Tube (CRT), liquid crystal display (LCD), gas-plasma display, and electroluminescent (EL) display. Other technologies, such as vacuum fluorescent displays (VFDs), electrophoretic displays, and light emitting diode (LED) displays are not in common use as computer interfaces, and are not widely used for producing colour images (Smarte, 1988). This section discusses the more commonly used displays which are associated with CRT technology and briefly describes some of the other available technologies.

3.2.1 Cathode Ray Tubes (CRTs)

A conventional CRT produces an image by directing an electron beam on a phosphorescent coating on the glass face or screen of the tube. When the electron beam strikes the phosphor, light is emitted. The intensity of the light will depend on the intensity of the electron beam, and the colour of the light will depend on the chemical composition of the phosphor. Once the electrons stop hitting the phosphor, the light quickly fades at a rate that depends on the persistence characteristics of the phosphor.

The electrons in the beam are produced from a heated cathode electrode, referred to as an electron gun, and they are shaped into a needle-thin beam by a strong positive voltage. This beam can be focused, aimed, and deflected by a control grid and a focus control unit made up of electromagnetic coils. Not all the energy from the electrons is converted into light. A large part is converted into heat, captured by the grid or the screen.

CRT colours are produced by additive mixtures of the colour phosphors. Consequently, only those colours that are the additive mixture of the phosphor colours (CRT primaries) can be produced.

Two types of CRTs that have been considered in the ATC environment include the shadowmask and penetration displays. These two types are described briefly below.

Shadowmask Displays

The shadowmask configuration is currently the dominant technology in colour video and is used in colour television. Shadowmask CRTs usually have phosphorous triads that light up in the three primary colours, (red, green and blue or "RGB"), and have three electron guns with three beams scanning the screen. The varying brightness in each of the primary colour pixels, as determined by the intensity of the respective electron beam, defines the overall colour of the triad, and this forms the overall picture on the screen.

Shadowmask CRTs usually use raster-scan drives to convert display information into the display picture. Deflecting coils direct the beams in a scanning motion horizontally across the screen for successive lines to produce the display image. Each time an electron beam strikes a phosphor pixel on the screen, it will do so with the required intensity and light up the phosphor with the exact degree of brightness. For normal television screens, the scanning rates are so high (15,750 Hz for horizontal and 60 Hz for vertical), that the eye sees only a total image on a screen.

The shadowmask is used to make sure that the three electron beams are focused precisely on the phosphor triads (which are typically only about 0.3 mm apart). Shadowmasks are metal screens with tiny holes that must be precisely aligned with the phosphor triads to prevent the beams from striking and illuminating other phosphor triads. Three of the most common geometries of shadowmask CRTs include (David, 1984a):

a. **Delta Guns**: the three guns are arranged at the corners of an equilateral triangle, irradiating phosphor dots arranged in a triad.

b. **In-Line Guns**: the three guns are arranged in a line, irradiating phosphor dots side by side. The lines of phosphor dots are offset from line to line, so that the dot pattern is identical to that of the delta gun.

c. **Trinitron**: an in-line gun configuration, but the phosphor is arranged in vertical stripes. The holes in the shadowmask are rectangular and oriented vertically.

Penetration Displays

Penetration displays use a cathode ray tube with two superimposed phosphor coatings on the inside screen surface. The colours emitted by the two phosphors are usually red and green. A range of colours can be produced by controlling the beam energy.

Precise points and continuous lines can be drawn with a penetration display. Symbols, lines and characters can be superimposed over each other, though the common portions may appear brighter or be of a different colour than the original items.

Penetration displays usually use random-scan drives to convert display information into the display picture. Random-scan drives control the movements of the cathode ray beam by directly controlling the *x* and *y* deflections, speed and the intensity of the beam. This is usually achieved by a specialized processor that sweeps through the list of display instructions.

3.2.2 Other Display Technologies

Unlike CRTs, the pixels in liquid crystal, gas plasma and electroluminescent displays are addressed directly. This feature allows flat screen displays, avoiding the linear distortion CRTs experience due to the angular sweeping of the electron beam. These technologies have the following characteristics:

a. **Liquid Crystal Displays**: An LCD pixel consists of a film made up of organic molecules which is somewhere between the liquid and solid state, sandwiched between two polarized filters. These "nematic" crystals respond to electric fields, and align themselves accordingly, making them in effect polarized filters that can be switched on and off. Depending on the orientation of the electric field or voltage, the nematic crystal will either block the light passing through the outer polarizers, or become transparent. This effect allows the creation of images through dots that are dark or light.

   Another technological advance is the active matrix or thin-film transistor LCD. The active-matrix LCD includes a thin-film transistor which is fabricated along with each pixel, and acts as a switch to turn on individual pixels. This significantly shortens response time, and has application in colour TV screens. Colour is added by using organic filters and backlighting. Full Colour LCD screens are currently available, but only in small sizes, 3 to 4 inches, for pocket television sets. Large colour displays are still at the research level.

b. **Gas Plasma Displays**: The active ingredient of a gas plasma pixel is a small cell filled with neon or argon-neon gas mixture, which becomes excited and glows when a DC or AC current is applied. A matrix of electrodes allows each pixel to be addressed individually. Recent advances now allow for a "grey" scale in the brightness or intensity of the pixels, allowing the shading of an image. Some manufacturers have announced larger (15-20 inches) full colour screens, with life expectancies similar to that of CRTs.

c. **Electroluminescent Displays**: Electroluminescent (EL) displays are also flat matrices of pixels, which consist of phosphors that emit light in the presence of an AC voltage. A typical EL display consists of a thin film of EL material, eg. a phosphor such as zinc sulphide with manganese, sandwiched between thin films of dielectric material. The front is transparent, while the rear is reflective. When the voltage is applied, this phosphor will emit a bright yellow light. Other phosphors can be used for different colours. A controller chip varies the brightness to produce a "grey" scale. Fully colour EL displays have been hampered by difficulties in producing a good blue phosphor.

d. **Three Dimensional Displays:** Some technologies are oriented toward capturing the third dimension. One approach is to build on the concept of binocular vision, a variation on the red-and-green glasses, or polarized glasses. One US company is exploring the use of special liquid crystal shutter (LCS) eyeglasses synchronized with a CRT display. Texas Instruments is experimenting with an electromechanical device that projects a low-power laser light onto a slanted 10-inch rotating translucent disc. The resulting 3-D image is in the volume occupied by the fast rotating mirror (400 to 600 revolutions per minute). By scanning the laser beam in two dimensions on the rotating disc, a viewer's eyes fuse the points of light into a "solid" object. The resulting image can be viewed from any angle and has a 4 inch depth of field. Full colour could be possible by using different coloured lasers.

ATC is seen as a potential application for this advanced technology. An entire airspace around an airport might be displayed, with air-traffic controllers able to walk around the scene, viewing it from different angles, and identifying aircrafts with small hand-held lasers (Smarte, 1988).

3.2.3 Hardware Issues

A number of issues relating to hardware present potential limitations for use of colour on displays. While many of the potential problems noted below can be overcome (and indeed, have been successfully overcome by some manufacturers) little information is available on the long-term properties of CRT displays. The substantial research that exists on the use of colour coding in ATC displays assumes the existence of stable, optimized display systems. With current technology, such systems are hard to find. However, the display manufacturers are making improvements in CRT display technology and it may not be long before solid state displays become available. For the foreseeable future, however, vacuum tube CRT display technology is the only cost-effective alternative. Some of the issues that may impact negatively upon colour coding schemes in air traffic controller workstation displays that employ CRT technology are addressed below.

Confound Between Colour and Luminance

Present day digital graphics display generators are represented as being capable of producing tens of millions of different "colours." This is misleading as an indication of the operational capacity of the display system. Of the colours that are available to the user, not all are equally useful in designing visual displays.

In spite of the impressive numbers of colours advertised for digital graphics displays, their useful colour gamut is restricted. A standard 8-bit pixel intensity scale applied to the digital to analog converters driving each of the three phosphors (R, G and B) yields an aggregate "colour" scale value of 24 bits (16.7 million "colours"). However, this scale has features that make the useable number of colours much smaller. First, calculated in this way, the colour scale is completely confounded with the luminous intensity scale. That is, every specific "colour" value not only has a specific chromaticity value associated with it, but also a specific screen luminance. In order that all symbols be of approximately the same intensity (so it would be possible to use the intensity scale to code for another attribute) it would be important to only use those colours that were at approximately the same

brightness level. This dramatically reduces the effective number of unique colours at any given luminance level.

Nonlinearities Between Screen Luminance and Chrominance

One of the major difficulties of RGB (Red-Green-Blue) monitors is a consequence of the fact that they depend upon the additive mixture of all three phosphors in any given spatial location in order to produce the specific colour required.

In a monochrome display, each individual location on the screen that can be addressed from memory is called a pixel. A high quality monitor design ensures that the amount of crosstalk from one pixel to its neighbours is as low as possible.

In an RGB monitor, each logical address location on the CRT screen is called a "trixel" to denote the fact that there are actually three pixels at that location--one red, one green and one blue. All achievable colours at that location are additive mixtures of these three pixels, each modulated by a unique amount. The colour seen at that location is the spatially averaged chromaticity and luminance of these three pixels. When viewed at a distance far enough away the light from each pixel phosphor in the triad mixes with its other two neighbours on the retina of the observer and a single point of colour is seen; rather than one red dot, one green dot and one blue dot, each with a different luminance. Thus, a white trixel would consist of each pixel in the triad being modulated at approximately the same luminance level and additively mixing to produce a "white" light.

In the useful operating range of the display, the higher the electron density the brighter the screen. The relationship between electron density and screen luminance follows the form:

$$L = k\Phi^{\Gamma}$$

where the exponent, Γ, typically varies from values of 1 to 2 across given display monitors from various manufacturers and models. A unit value of Γ means that the relationship between DAC (Digital to Analog Converter) input voltage and screen luminance is linear. Departures from linearity (gamma values are typically >1) make calibration more difficult. However, when each primary beam circuit is a different gamma the amount of digital processing time required for high colour image fidelity can become excessive.

The problem can be described as follows. A specific chromaticity may be produced at one luminance level by sending three unique electrical values to the circuitry driving the R, G and B electron guns (that, in turn each excite one of the three phosphors in a specific luminance ratio, $L_r:L_g:L_b$). To make a brighter version of that same chromaticity the luminance ratio must remain constant, although the absolute electron density will increase proportionately:

$k\ (L_r:L_g:L_b)$, where k is a scaling constant

This equation will only work, however, if the gamma of each of three primary circuits is equal to the others, otherwise a separate scaling function must be applied to each gun:

$(k_1L_r:k_2L_g:k_3L_b)$

This triples the number of multiplications that must be performed in order to maintain colour fidelity across different luminance values. When the gamma does not equal 1, however, the problem becomes more severe as each value of k_i has to be computed by numerically evaluating a second-order polynomial equation. Gamma correction circuitry is often used to avoid this problem.

Instability

Any specification of the use of colour in displays presumes that the display systems are (a) capable of producing the chromaticities in the specification, and (b) stable enough over time to keep producing the chromaticities in the specification. Problem (a) is straightforward to solve in that the specification can be written after the characteristics of the monitor are known. Problem (b) is not straightforward as stability can only be measured after installation, unless nominal colour stability data have been taken by the manufacturer.

Instability in achieving a specific gamut of colours is most often caused by three problems:

a. Changes in the performance characteristics of the CRT display phosphors through aging and through "burning" due to prolonged driving (often resulting in inhomogeneity of the colour and brightness gamut over the entire screen surface);

b. Instabilities in the display power supply;

c. Instabilities in the digital-to-analog converter circuitry of each of the electron beams in the monitor.

Each of these factors can affect the ratio of luminous emittance of the different phosphor types (RGB if a trichromatic monitor or RG if a penetration monitor).

Blooming

One consequence of the physics of CRT technology is the inverse relationship between screen luminance and display image quality. In order to achieve high screen luminance, as noted above, greater numbers of electrons must be used to excite the phosphor coating on the CRT glass envelope. Unfortunately, the greater the number of electrons, the greater the number of "stray electrons" that will bombard nearby pixels. When the density reaches sufficiently high values, these strays are seen, producing an effect referred to as "blooming." Because these pixels are excited, but not addressed, they can only contribute to the degradation of the image viewed. When the luminance of the screen must be as high as possible (necessitating modulating the phosphors with high electron densities) more than one of the elements of the trixel must be excited.

Because of this arrangement in the RGB monitor, the issue of crosstalk causing image degradation is more complex because there are now two types of blooming effects: those within a single trixel and those between adjacent trixels. Both types have implications for the use of colour coding in ATC displays. The within-trixel effects cause distortions in the chromaticity of the triad of phosphors that

make up the trixel. In order to generate a given chromaticity each of the three phosphors of the trixel must be excited to its own specific value. As crosstalk between adjacent phosphor dots of different colours typically depends upon the electron beam density, the higher the modulation of the beam the greater the distortion produced. Between trixel degradation reduces spatial image fidelity. Clearly, both can produce severe problems for the display if not carefully monitored.

The standard means around these problems is to specify the exact RGB intensity values to be used and to lock them into the software. Periodic checking of the monitors with the use of a test pattern can help to detect drift before it becomes a problem. Recalibration methods can be used to circumvent the problem of having to replace an expensive monitor in order to be able to use the same colours. Drift in the monitor circuitry can be compensated for to a certain extend by software changes.

Image Misregistration

Because of the geometric relationship between the electron gun(s) and the phosphor coated screen that is excited by the gun's emissions, all display monitors produce distortions of the image. The distortions typically increase towards the edge of the display. With an RGB monitor, this problem is compounded by the fact that each of the three images is a monochrome image produced in one of the phosphor primaries, Red, Green and Blue. As expected from the above discussion, each of these images will become distorted towards the edge of the display. Unfortunately, however, the distortions produced in each image are often unequal. This is called misregistration. Misregistration can produce disastrous effects upon image quality.

Another problem that results in image misregistration is "doming." Doming occurs when the shadowmask heats and expands because of the large energy density in the electrons it stops. The expansion is usually not uniform across the shadowmask, and its resulting shape accounts for the term "doming." The distortion of the shadowmask holes causes misregistration and uniform colours become non-uniform. Trinitron tubes use a tensioning wire to reduce the effects of this problem.

Shadowmask Magnetization

Magnetic fields build up in the shadowmask when the electromagnetic forces produced by electrons, assisted by the heat build-up, create areas of magnetic field. These areas are non-uniform and usually produce large regions of non-uniformity in colour or brightness on the screen. Most displays have automatic degaussing activated at start-up of the system to remove these magnetic fields (Cowan, 1987).

Large Screen Displays

The needs in computer aided design, image processing, graphics specialties and other applications are pushing the technology to larger screens and higher resolution, approaching photographic resolution. Large screen colour displays have been recommended for use in both the Canadian and U.S. ATC environments. There have been some concerns regarding use of these displays having greater than 2000 x 2000 pixel resolution, both from the point of view of reliability of the technology and effects on the users. The large size and high resolution require the doubling of beam voltages and writing speeds with the associated increase in power supply. The high voltage and high frequency power supply are potential sources of hazards for users (Paul, 1986).

3.3 Human Vision

The physical properties of the human visual system combine with the perceptual and cognitive capabilities of the user when interacting with a display screen.

Ideally, computer displays would provide users with visual characteristics that they encounter in the natural world, for which the human visual system is designed, i.e. small spatial detail, no flicker, and a virtually infinite range of colours. Unfortunately, cost, technology and design logistics limit the way in which we can present information on a computer screen.

The characteristics of human vision that are most involved in interaction with display screens are the spatial, temporal and chromatic domains. These areas, as well as the physical characteristics of the eye, are discussed in the following sections.

3.3.1 Function of the Eye

The basic function of the eye in receiving visual signals concerns the cornea, the lens and the retina. Light rays passing through the cornea and the lens are bent to converge at one point in the eye. Most of the bending occurs at the surface of the cornea, and finer adjustments are achieved by changing the shape of the lens through muscular action. The cornea and the lens together serve to focus the image of the incident object on the retina. The retina is a thin layer of neural tissue that makes up the curved photosensitive surface at the back of the eye. The retina includes two types of receptor cells, rods and cones.

The cones are concentrated at the fovea (near the centre) of the eye. The fovea is the only area in which the optical image is sharply in focus partly because the outer layers of the retina are absent and the incident light falls directly on the cones. The ratio of nerve fibres to cones is high, particularly as one approaches the foveal area, giving the cones high spatial resolution. Therefore, foveal cone cells have relatively direct lines to the brain so that there is little convergence along the neural pathway. This condition provides precise information about the area of the retina that has been stimulated, and the visual acuity attributable to cones is high. Because of the lack of neural convergence in the cone pathways, however, high levels of illumination are needed for their activation, making cones functional only in "daytime" lighting conditions.

The rods for the most part are concentrated away from the fovea, with their highest density at approximately 15 to 20 degrees off the visual axis. There is a much higher level of convergence in the rod visual pathway than for the cones. Though this means that visual acuity from the rods is poor, spatial and temporal summation are good. This, together with the fact that the light has to pass through the retinal layers before falling upon the cones, reduces the ability to discriminate detail toward the edges of the visual field.

The detection of colour in the visual field is attributable to the cone cells in the retina. The sensitivity of individual cones to colours varies. Different cones have different maximum sensitivities to different light wavelengths. The peak sensitivity of approximately two-thirds of the cones occurs at a wavelength of 575 mμ which is in the yellow portion of the visible spectrum. Most of the remaining cones have a peak sensitivity at approximately 535 mμ which appears yellow-green. Approximately

2% of the cones react to much shorter wavelengths in the blue portion of the spectrum at about 445 mμ (Galitz, 1989). The perceived colour of incident light on the retina is a result of the extent and proportion of which of the various types of cones are stimulated.

3.3.2 Spatial Vision

Spatial vision is the ability of the visual system to resolve patterns of various sizes. The conventional measure of spatial vision is visual acuity (Borish, 1975). While a tremendous body of knowledge has accumulated on the factors that influence visual acuity, there are other measures of spatial vision that have proven to be useful under a variety of conditions. Among the most important of these is the sensitivity of the human visual system to the luminance contrast of objects of various sizes (Campbell and Green, 1965; Campbell, 1974). The optimal execution of visually guided behaviours depends upon the availability of sufficient luminance contrast components in visual patterns over a range of different spatial frequencies (Leibowitz et al, 1980).

On a video display screen, spatial vision refers to the distribution of photic variations (vertically and horizontally) in the visual field. Spatial resolution can be categorized into two processes: detection and recognition. Detection refers to the ability of the observer to distinguish the presence of a target against a homogeneous background while recognition refers to the capacity to discriminate the stimulus from a number of alternatives. Both detection and recognition play a role in visual information processing tasks.

It is surprising to discover how different the spatial vision of the centre of gaze is when compared to that of the peripheral visual field. As an example, it is instructive to fixate a single word in the middle of this page and, without looking away from that word, to try to read the others nearby. After doing so, one is impressed with the dramatic falloff of visual acuity away from the point of fixation.

The small region of the retina responsible for our best visual acuity is called the fovea and subtends a visual angle of about one degree (about the size of your thumbnail when viewed at arm's length). When viewing a video display from a distance of approximately 20 inches, "the area within a third of an inch or so of the centre point is viewed entirely with the cones, while the outer edges of the display are viewed entirely with the rods" (Snyder, 1988).

Though visual acuity is reduced in the peripheral visual field, a person is still aware of and assimilating stimuli in this region. The visual capacities of this area, however, are quite different from those of the fovea -- so much so that it has been postulated that there are effectively two visual systems within the brain, one of which takes information regarding the location and relative movement of large objects from the periphery (Schneider, 1969). This secondary system provides inputs to eye movement control systems. Stimuli in the periphery may cause a user to turn and view the new event with their foveal vision. In other words, the stimulus characteristics that best drive the foveal visual system are not the ones that best drive the periphery.

This finding, and the fact that the area of the display in the periphery is greater than that of the centre, means that large format displays should probably not have homogeneous information density arrayed upon them. If peripheral stimuli on the display are coded in the same way that the central stimuli are coded, the amount of visual attention that a viewer must use to monitor the peripheral

component of the display will have to be significantly greater than that needed for the foveal area. This is because significant head and eye movements will have to be executed in order to scan the edges of the display field with foveal vision. An optimal design would incorporate stimulus properties for peripheral vision that are best suited to detection/recognition by peripheral vision mechanisms. While some suggestions have been made that increased brightness in the periphery would help to counteract this difference (Murrell, 1965), increased size, altered shape, colour and motion are likely to be as effective and more readily implemented on CRT display technology.

3.3.3 Temporal Vision

Because of the nature of the uses for video displays, information which they display typically changes over time. Temporal vision refers to the processing of such time dependent information. The display should be refreshed at a sufficient frequency to indicate changes in this information without causing 'flicker' perceptible to the human observer. For technologies such as the cathode ray tube (CRT), the display has to be refreshed to maintain adequate luminance because of the decaying nature of the image. Sensitivity to flicker varies with adaptation level, field size, target luminance and position in the visual field.

The visual system is more sensitive to flicker in the peripheral field than in the foveal field. Screens with high luminance levels in the peripheral field, such as those with dark characters on light backgrounds (D/L polarity), will have different flicker characteristics than those with low luminance in the periphery (light characters on dark backgrounds (L/D polarity). For screens with D/L polarity, refresh rates of 95 Hz or greater may be necessary to eliminate flicker completely as opposed to the 50-60 Hz usually used (Tijerina, 1984).

The integration time of the eye is also a factor in determining suitable refresh rates. The eye integrates light energy over the duration of a stimulus up to a maximum time. The requirement for refresh rate is a direct function of this integration rather than of the momentary energy level itself. This time duration has been shown to be approximately 100 ms for both the foveal and peripheral areas. Flicker is known to affect visual acuity (Bartley and Ball, 1968).

3.3.4 Colour Vision

A large body of evidence has accumulated to support the contention that normal human foveal vision (the vision at the centre of gaze) is trichromatic (Boynton, 1979). This means that only three variables are needed to specify the relationship between the physics of light and the visual sensation of colour. At the outset of the physiological process, visible radiation is absorbed into the outer segments of three different types of retinal photoreceptors in the fovea of the eye. Each type broadly absorbs light of different wavelengths, but each type has maximum absorbance at a location in the spectrum different from the other two. Thus, while any given light may be absorbed by all three photoreceptor types, the ratio of absorbance in each of the three types will be different for most wavelengths in the spectrum. This fact is the key to colour vision, for a different ratio must be produced by the three photoreceptors for every discriminably different colour.

It follows from this that any two lights producing the same ratio of response in the three different photoreceptor types will be seen as the same colour, irrespective of the composition of spectral energy

distribution of each light. There are many physically different lights that can give rise to the same ratio of responses of the three photoreceptors. This fact provides the basis for colour television, because, by varying the luminous intensity of only three primaries it is possible to reproduce a large (but not complete) gamut of colours. This fact also makes pattern vision impossible for dichromats under conditions of equal luminance since such conditions match the responses for the two remaining photoreceptor types they possess (Tansley and Glushko, 1978).

The mapping of radiant energy onto the perceptual experience of colour, however, is complex and beyond the scope of this report (for example, see Burham, Hanes and Bartleson, 1963; Bartleson, 1980). Nevertheless, it is important to be able to specify precisely the radiant quantities that are needed to give rise to a particular stimulus if standards are to be maintained within a given application.

Radiant energy is described in terms of wavelength or frequency. Those wavelengths that compose the visual spectrum are between approximately 400 and 700 nanometres. Different wavelengths within

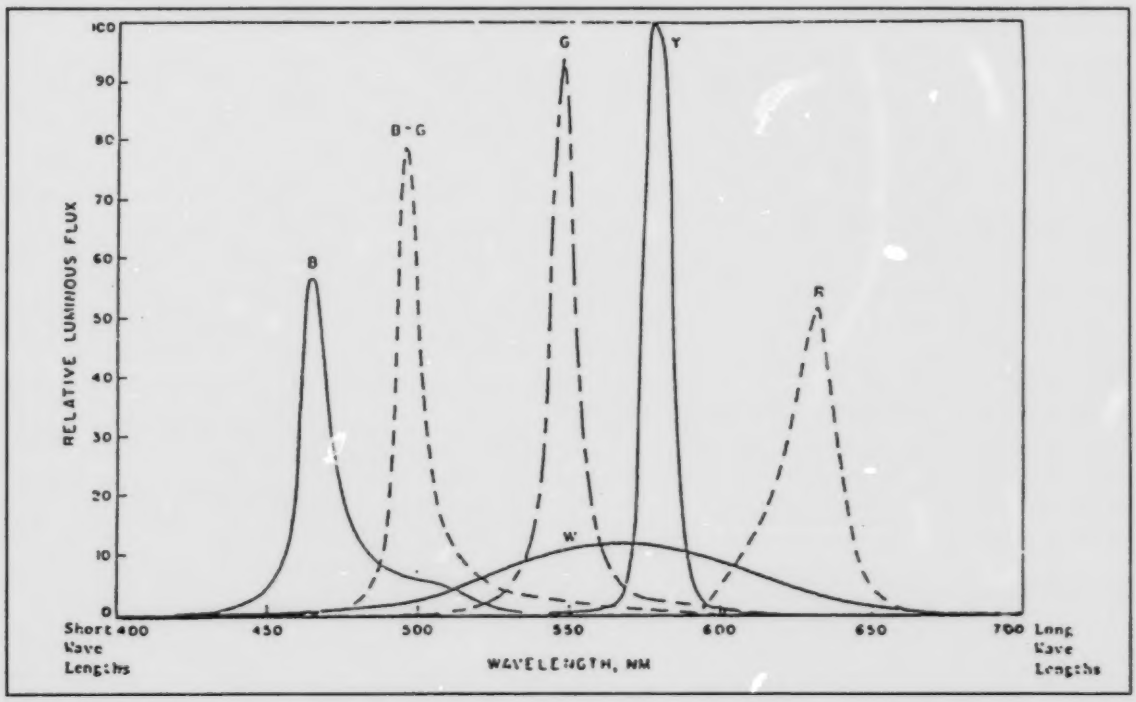

FIGURE 1: Examples of Spectral Energy Distributions (Kinney, 1978)

the visual spectrum are associated with perception of different colours. Spectral Energy Distributions (SEDs) refer to the distribution of light energy among wavelengths in a colour stimulus. Some examples of SEDs and their associated colours are shown in Figure 1 (Kinney, 1978).

Colour has a number of measurable quantities that can be associated with display screens. These include wavelength, purity, and luminance (Wyszecki, 1982). The human perceptual quantities associated with these are hue, saturation, and brightness. To use colour in an effective way on a display, the relationships of these quantities to the visual task performance of the ATC have to be considered.

Colour and Accommodation

Accommodation is the ability of the eye to focus objects on the retina at different distances from the eye. Accommodation is achieved by changing the shape of the lens which becomes thicker and more curved the closer the object is to the eye. Even under steady stimulus conditions, the accommodative mechanisms is known to fluctuate (Campbell, 1959). Monochromatic (or narrow-band) light is refracted differently by the eye according to wavelength; a situation referred to as chromatic aberration (Wyszecki and Stiles, 1982). The implication of chromatic aberration is that accommodation as well as convergence must change to bring objects of different colours into focus. This additional effort could contribute to visual fatigue.

Because of axial chromatic aberration the optics of the eye cannot focus the long wavelength component of a retinal image at the same time as that for the short wavelength component. Concern has been raised about the wisdom of simultaneously presenting visual stimuli in light from the extreme ends of the visual spectrum (e.g., characters or symbols presented in either red or in blue), because refocussing between the different coloured objects would be necessary. In the normal human eye about 1.5 dioptres of accommodative effort would be needed to change focus between two such objects without the assistance of a corrective lens.

Most of these effects have been produced under restricted laboratory conditions (e.g. with subjects viewing narrow-band colours with one eye only). During viewing black and white printed materials it is rare for observers to report coloured fringes (which would be expected due to chromatic aberration). The reason why such reports are rare is poorly understood, since there are as many more wavelengths out of focus in a white light image than in only two monochromatic images. There seems to be little evidence, that "multicolour displays upset or disable the accommodation system under normal binocular viewing conditions" and "researchers have not been able to find a link between the frequency of changing accommodation and visual fatigue" (Weitzman, 1986).

Studies involving prolonged viewing of chromatic displays have found minimal changes in the neural and focusing responses to different colour foreground/background combinations over time (Lovasik, 1989). Similar studies for subjective discomfort in prolonged viewing found "no support for the general recommendation to avoid the use of red and blue stimuli, either alone or in combination, in CRT displays" based on performance data (Matthews, 1989).

While it is known that the refractive capabilities of the human eye are wavelength dependent, most phosphors used in CRT displays are relatively broadband. Broadband radiation necessarily stimulates more than one photoreceptor type and, thus, provides a greater stimulus to accommodation. However, the consequence of a more even ratio of stimulation among all three photoreceptor types is a desaturated colour appearance (i.e., a colour that appears closer to white). Colours produced by the additive mixture of two or more phosphors are similarly less influenced. Due to these facts, it appears

unlikely that multicolour CRT displays will cause increased visual fatigue through an increased load on the accommodative system.

Visual Acuity and Colour

Visual acuity is the ability of an individual to visually discriminate fine spatial detail in a stimulus. Assuming the stimulus conditions to be suitable for accommodation (Charman and Tucker (1977), visual acuity depends upon:

a. The quality of the image projected upon the retina, which is dependent upon the optical components of the eye; and

b. The neural factors associated with visual image processing.

The refractive components of the eye are not always matched to the eye's axial length and, thus, corrective lenses are often prescribed to help bring the retinal image into focus at the plane of the retina. Reductions in visual acuity due to opacities of ocular media are more difficult to correct and, at present, nothing can be done to correct visual acuity deficiencies due to neural components of the retina or visual pathway except to externally magnify the retina image. In doing so, the advantages of compressing information into a relatively small visual field size are lost.

Due to the operating characteristics of visual pathway, two major stimulus factors play a role in determining an individual's visual acuity: the luminance contrast of the test target and the background against which it is viewed and the adaptation level of the visual system. Within the limits of indoor lighting, in both cases, generally the higher the value the better the visual acuity. Other factors have been shown to play a role, including the form and colour of the object under view (Charman and Tucker, 1978a,b).

Assuming that a person's refractive status has been optimized, there are a number of factors relating to colour that can mitigate against maintaining optimal visual acuity in a given situation. Reduced visual acuity associated with blue light sources can be largely attributed to the low density of blue sensitive cones in the retina (Weitzman, 1986). Consequently, the use of short wavelengths to produce display items of small angular subtense such as alphanumerics should be avoided. Using blue light to colour code symbols should only be attempted when the symbol size is greater than about 1/2 degree. Simply by increasing the luminance offset, the reduction in visual acuity will not be successful because of the increased level of intraocular scatter of short wavelengths. Using a desaturated colour in larger format, such as in a background, would be a more suitable application.

Brightness and Colour Sensitivity

The retina is not equally sensitive to light of all wavelengths. Therefore, different colours of equal radiant intensity will appear brighter or less bright to the eye according to their wavelength. The brightest spectral colour to the light adapted eye is at about 555 nm which is a yellowish-green. Brightness progressively decreases as the wavelength approaches either end of the visual spectrum. Since the turn of the century the science of photometry has accounted for this fact by weighting the radiation of a given light by the spectral sensitivity of the eye. The photometric quantity known as

luminance, thus, takes the unequal sensitivity of the human eye to all wavelengths into account. Photometric measurements are always used when specifying light as a quantity for vision (I.E.S Lighting Handbook, 1987).

The variation among individuals of perceived brightness is greatest at the extreme ends of the visual spectrum (Kinney, 1978). This implies that luminance settings in these regions will be perceived differently by different individuals. Where brightness discrimination becomes important, matching stimuli of different colours for their brightness (heterochromatic brightness matching) is required. Heterochromatic brightness matching is technically difficult but can be realized on CRT displays where sufficient dynamic range exists.

Colour Discrimination

As a consequence of our understanding of the relationship between various components of the visible spectrum and their effects upon the retina an internationally accepted system of measurement methods and standards has been developed and is in wide use today. This system, known as the CIE system of colorimetry (for Commission Internationale de l'Eclairage), can be used to measure radiation in terms of its relationship to visual sensation. Quantities of photic radiation are, thus, converted into the appropriate mathematical representation (Wyszecki and Stiles, 1982; Bartleson, 1980).

The Commission Internationale de l'Eclairage (CIE) is an international organization responsible for colour standards. The CIE provides a chromaticity system by which colours can be specified, measured and reproduced. The basis of this system are the CIE chromaticity coordinates which are determined by choice of primaries (tristimulus because CIE expresses the colour in terms of an additive mixture of three primaries), colour matching functions of a standard observer (empirical), and the spectral power distribution (measured physically). The three chromaticity coordinates in the CIE system always sum to 1. Therefore, the third coordinate is specified by the other two. Further discussion of the CIE chromaticity system is provided in Appendix B.

The results of the discussion in Appendix B are that equations are available to determine chromatic differences necessary to maximize perceptual discrimination (the CIELUV equation) and to enhance symbol legibility by displaying one colour against the background of another colour (the $\Delta E_{u'v'}$ legibility equation) (Snyder, 1988).

Retinal Colour Areas

Colour vision in the peripheral field is known to be different from that of the central foveal region, where most of the data on human colour vision have been obtained. As was discussed in Section 3.3.1, different cone receptor cells in the eye have different sensitivities to different input colour light sources. Correspondingly, different areas of the retina are more or less sensitive to different colours. Figure 2 shows the regions of the peripheral visual field where the colours red, green, yellow and blue can be identified. In the extreme periphery, it is found that yellow and blue colours are more accurately perceived than red and green. The sizes and shapes of these areas depend on adaptation level and luminance of the targets under consideration and can differ between people with normal colour vision and between the left and right eyes of the same individual.

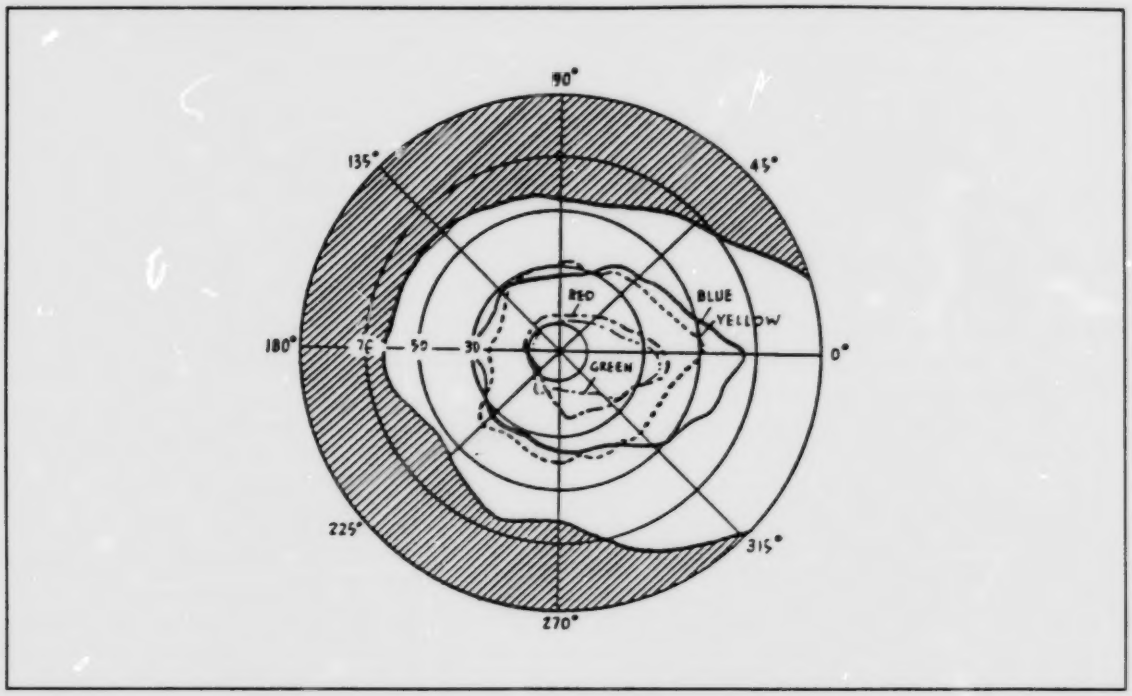

FIGURE 2: Retinal Colour Sensitivity Areas (Woodson, 1981)

Sensitivity to colour in the visual field can be mapped onto a display surface by knowing the display's areal extent at a given distance. Results of such calculations show that "when both eyes are fixed at one point on the display surface, large display areas lie outside the areas of colour sensitivity" (Kinney, 1978). When the viewer moves closer to the display, these outside areas become still larger. This result relates to our statement earlier that coding strategies for the optimum detection of visual stimuli presented in the peripheral fields must acknowledge the differences between peripheral and central vision. When attempting to provide an alerting stimulus in the periphery, for example, colour coding alone will not be sufficient . However, combined with flicker, motion or size changes colour coding may assist in capturing visual attention from the present centre of gaze to a more peripheral location in the visual field.

3.3.5 User Population

Controllers in Canada are currently subjected to colour vision screening through the administration of the standard Ishihara colour plates tests for colour identification. If they fail these tests, further colour lanterns tests may be used, or a practical test involving operational conditions are used. Failing all these tests, they are not eligible for operations in the ATC environment.

A significant proportion of the general population has some form of colour perception deficiency (~8 % of males and ~0.5% of females) (Galitz, 1989). These deficiencies even occur in professions that

require a high level of visual fitness. For example, approximately 1% of Class I pilots in the U.S. have medical waivers for colour deficiency, and the extent of their deficiencies is unknown. Some tests for normal colour vision will pass individuals with mild or moderate colour deficiencies, particularly of the red-green type. (SAE, 1989) Therefore, even individuals considered to have normal colour vision may have a wide range of variability in their actual colour vision performance. The level of colour deficiency in the Canadian air traffic controller population needs to be investigated further. Since some colour deficiencies may not be detected with the tests described above, some consideration of the characteristics of people with colour abnormalities is worthwhile.

Most colour deficiencies appear to be genetic due to a sex-linked recessive gene, though some can be caused by trauma, disease or exposure to substances. As a result, a small but significant proportion of the male population is missing at least one of the retinal photopigments required for normal colour vision. People with colour deficiencies are generally categorized as monochromats, dichromats and anomalous trichromats. As monochromats are extremely rare, only the remaining two are considered:

a. Dichromats (about 2% of the population) lack one colour dimension. Red-green dichromats (the majority) can perceive the colours blue and yellow, and white, grey and black. Blue-yellow dichromats perceive red and green, and white, grey and black.

b. Anomalous trichromats (about 6% of the population) have some, but not total loss of a colour sensitivity. Most have defective red-green systems, while very few (0.002%) have defective blue-yellow systems.

Aging of the visual apparatus may also be responsible for some acquired colour defects. The lens of the eye often becomes yellowish with increasing age, reducing the colour discrimination capability for those colours containing blue (SAE, 1988). Also systemic diseases such as diabetes can cause retina damage manifested by colour vision losses.

An additional and well known effect of aging on vision is that the range of accommodation is reduced. This reduces the ability to focus wavelengths on the extreme of the visual spectrum, such as red and blue.

3.4 Visual Function in ATC

Air traffic controllers rely heavily upon visual information processing to perform many of their tasks. It follows that careful consideration should be given to the introduction of a new visual parameter into their work environment. As with most changes effected upon an existing work environment, there will be both positive and negative impact upon the various subcomponents of the job. While the ultimate acceptance or rejection of any specific use of colour coding scheme will depend upon on-the-job experience, recommendations can be made in advance that will guide workstation designers towards an optimized solution. In the following section we discuss the range of conditions where colour might be used for coding purposes.

3.4.1 Types of Stimuli

The air traffic controller views a work surface containing various displays of visual information. The successful performance of visual tasks requires visual scanning of the environment along with detection and recognition of the appropriate visual information. Pertinent visual stimuli for the controller task can be classified into four categories:

a. **Permanent features of the displays**: Examples of these include the basic format of the display, its colour gamut, operating luminance and aspect ratio; the permanently installed graphics such as radio beacon positions, lane markers etc.

b. **Temporary features of the displays**: Examples of these include the presence and position of various aircraft detected by radar and associated data blocks; specific weather conditions and other variable states (such as emergency conditions, variable regulations in force, etc.).

c. **Permanent features of the surrounding environment**: These include the basic layout of the facility; ambient lighting and sound levels; layout of the work surface and immediate work environment in which the ATC console is located, etc.

d. **Temporary features of the surrounding environment**: Examples of these features include the presence of additional personnel; materials and objects near or on the work surface; additional displays or equipment moved into the work environment, etc.

This classification gives insight into the types of visual tasks needed during air traffic control and the implications for controller performance under conditions where the availability of the various types of visual information is altered, distorted or eliminated. The main concern for use of colour for coding of information would appear to be found in categories a) and b), above, but it is important to note the potential of categories c) and d) for providing various forms of interference with colour coding.

3.4.2 Colour Perception

Accurate object colour perception requires four elements:

a. The observer must be trichromatic;

b. The observer must be gazing directly at the coloured object;

c. There is sufficient illumination for photopic light adaptation; and

d. The visual angle subtended by the retinal image of the object of regard must be greater than about 1/4 degree.

To a certain degree, colour vision depends upon the spatio-temporal characteristics of the stimulus. The colour of very brief and/or very small chromatic stimuli are more difficult to detect and/or correctly identify than are larger stimuli of longer duration. For example, normal trichromatic

individuals behave as colour blind observers when viewing very small objects or objects placed in the extreme periphery of their visual field.

Colour can be used to increase the information density of a stimulus array, but its use is controversial because of the incidence of colour vision deficiencies in the general population and because colour coding is not equally effective under all conditions of illumination.

Normal colour vision is not possible under scotopic levels of illumination. Consequently, where colour vision is required, artificial illumination must be provided to stimulate the photopic photoreceptors. The discrimination of one colour from another may be impaired as a result of a restriction in the stimulation necessary for optimal colour discrimination. This often occurs under energy efficient artificial lighting.

3.4.3 Visual Tasks of Air Traffic Control

Air traffic control places demands upon visual function. The visual subtasks involved in ATC are outlined below:

DIRECT FUNCTIONS: (directly related to visual perception)

a. **Visual Attention** - affected by perceptual set; degraded by increasing task load and mental status.

b. **Visual Detection** - dependent upon conspicuity; degraded by environmental conditions and mental status.

c. **Visual Recognition** - dependent upon visual information content; degraded by environmental conditions and mental status.

INDIRECT FUNCTIONS: (dependent upon visual information)

d. **Decision Making** - affected by total task load, a function of speed, traffic congestion, and mental status.

e. **Visually Guided Responses** - affected by total task load, speed and by mental status, possible responses limited by previous responses and by the future consequences.

These functions are further described in the sections below. The reader is encouraged to refer to several excellent reviews for further details (Bartleson and Grum, 1984; Boff et al, 1986 a,b; Boyce, 1981; Salvendy, 1987; Van Cott and Kincade, 1972).

Visual Attention

It has been found that the effective visual field over which the observer can attend to incoming information becomes more heavily weighted to the fovea (Easterbrook, 1959; Williams, 1982).

Attention is the capacity to selectively "tune in" to certain stimuli and to "filter out" certain others and to be able to voluntarily switch the attended stimulus. Humans have both limited attention and limited visual information processing capacity. As a consequence, one is incapable of continuously attending to all potentially relevant features in the visual scene. The way in which this limit might be overcome is by regular sampling from the wide variety of locations where potentially relevant visual stimuli might occur, by storing these visual samples in memory and by periodically "upgrading" them.

Of all the information available during the performance of air traffic control work, the controller somehow chooses to attend to specific elements of information and to selectively ignore the rest. How this is done and what happens to this capacity when he/she becomes fatigued is of interest and concern to those studying the performance of skilled behaviours. We consider, below, the role that higher attentional mechanisms may play in providing information to cognitive processes which presumably mediate the performance of these skilled acts.

Visual attention has three basic functions:

a. "Foveation" or the directing of the gaze of the eyes to a location of interest under control of peripheral visual mechanisms based upon previous information input,

b. The modulation of central attentive variables associated with the processing of information from a number of sensory modalities, and

c. The encoding and storage of information obtained through the visual channel.

Kahneman (1973) presented a limited-capacity model of attention based upon the notion that the supply of effort in central information processing mechanisms is a negatively accelerating function of demand. If the requirements for the given task on attentional processes are minimal relative to the total capacity of the system, a considerable amount of spare or reserve capacity remains that enables the subject to perform other tasks more or less simultaneously. However, as the capacity demanded by the first task increases, the relative proportion of reserve capacity decreases.

Kahneman argues that the quantity of capacity or attention available at any given moment is a non-monotonic function of the arousal level of the individual; a concept known as the Yerkes-Dodson law. The Yerkes-Dodson law suggests that there is an optimum level of arousal for each task under consideration and that modulation above or below the optimum level of arousal for a specific task will result in a decrement in the performance of that task.

In the early phases of information processing, part of the total system capacity is automatically marshalled toward the acquisition of information from the environment while in later stages more of the capacity is allocated through voluntary control. This model has important implications for the use of colour. Research suggests that when the task is appropriately designed the colour attributes of objects can rapidly and (possibly automatically) modulate visual attention (Triesman, 1982; Bundesen and Pedersen, 1983).

Attention mechanisms can be thought of as representing an intermediate step between the initial encoding processes of the sensory mechanisms and cognitive processes associated with perception,

learning and memory; a means of automatically allocating limited information processing resources where most needed -- to incoming stimuli carrying high information content. Learning is a means of reducing the information processing requirements necessary to evaluate incoming sensory input.

As the efficiency of information processing increases (i.e., as more and more environmental events can be predicted from less and less incoming information) the probability of adaptive behaviour in any given situation increases and the allocation of limited visual information processing capacity may be made to other information sources. As learning progresses, efficient coding schemes may be used to reduce workload. In this case, colour may not be useful when acquiring the skills to perform a task but may become very useful when those same skills are highly overlearned.

In the context of the air traffic controllers workload, at any given moment in time, the controller is involved in the completion of a number of tasks and the proportion of total capacity or attention that is devoted to each of these tasks is allocated by a number of factors including momentary intentions, arousal level and an ongoing evaluation of the demands of performance of the tasks upon the capacity available. The so-called allocation policy is modified by various inputs depending upon the nature of the inputs and their relation to ongoing activities.

The time required to accumulate sufficient information to make the necessary decision is dependent upon the task's complexity. Information sources for each task are sampled periodically rather than continuously to see if the threshold for decision and reaction has been reached. Therefore, air traffic control may be thought of as including a supervisory process which evaluates the needs for information based upon the hierarchy. Once information needs at a given level are temporarily met, the needs for the next level in the hierarchy are attended to, and so forth.

As a general rule, the optimum level of arousal for complex tasks is higher than that for simple ones. This notion was accommodated into the Yerkes-Dodson relation by Easterbrook (1959) who proposed that an increase in the arousal level results in a restriction in the domain of inputs that the central nervous system will utilize for determination of further behaviour. Given this finding, colour coding might be useful under conditions of increased arousal by increasing the perceptual salience of specific portions of the display. This is known as increasing conspicuity.

Visual Detection

One's visual experience of the display environment is characterized by a perceptual continuum from detection to recognition of objects. The detection process is characterized by progressive differentiation of the visual field. The detection threshold of a target or object is generally taken as the minimum luminance contrast of the target against its surround necessary to become aware that "something" is present in the visual field. For small objects, the detection threshold is usually at a lower contrast than is required to correctly recognize it.

The likelihood of detection of a foveal stimulus is dependent on five factors:

a. The luminance of the object;

b. The object's luminance contrast with its immediate surround;

c. The object's spatial and temporal properties;

d. The number of "similar" objects in the visual field; and

e. The viewing or observation time.

Each of the factors can be varied so as to reduce the visibility of an object to a threshold level on the detection/recognition continuum; a level that can be measured through reference to the measurements of the physical parameters of the test stimulus used.

The conspicuity of a stimulus relates to the ease with which the presence of a visual stimulus is capable of attracting the observer's attention. A conspicuous stimulus has a high probability of being detected in comparison to a less conspicuous one. The conspicuity of a stimulus is a function of the physical stimulus values that influence the visibility of the target, including its luminance contrast, colour, shape and location within the visual field and the perceptual set of the observer.

The visibility of information is estimated by measuring the physical parameters of both the stimulus and its surround. Relevant measurable stimulus parameters include size, shape contrast, luminance, luminance contrast, and colour contrast. There are also important physical characteristics of the surround that influence target visibility. These include the number and spatiotemporal characteristics of the visual elements in the surround, their density and their proximity to the target. The location of a stimulus within the visual environment will also influence its probability of detection. In general, a target is more detectable the closer it is to the visual axis and the closer its actual location is to its expected location. The colour of the target is not as important for estimation of its detectability as its contrast.

The extent to which a given stimulus is attended, once it has been detected, is partially related to the information content of that stimulus. As content in a stimulus increases, so does the probability of the observer's attending to it. However, this relationship only holds over a limited range. The ability to "make sense" out of an incoming visual stimulus is partially a function of the observer's familiarity (i.e., prior experience) with it. When the observer is capable of remembering relevant previous experiences and associating them with incoming sensory inputs it is possible to make comparisons between the incoming information and stored information that permit the organization of adaptive behaviours in advance of the instant in which they are needed.

Visual Recognition

Visual recognition is the ability to comprehend more of the perceptual details in a stimulus than simply, "where" and "when" it occurred. The recognition of a visual stimulus is believed to require more cognitive activity than does its detection because memory plays a more important role in the recognition of an object.

One model of early visual information processing postulates that the detection and recognition of events and objects is an iterative process involving a comparison in the central nervous system of stored memories and incoming visual signals. The process attempts to match specific visual features of the unknown stimuli with information stored during prior experiences.

As discrete elements (e.g., line segments, shapes, colour, etc.) are assembled into sets of features, a search through memory is initiated for items with similar features. In the event no association is made, a loop is established that contains the earlier attention and detection stages with the result of obtaining more visual input for comparing to prior experience. Of course, additional sensory input may lead to a revised set of features which can alter the memory search, forcing this comparison process to undergo several successive iterations.

The point in time at which recognition occurs may not be the earliest point at which such recognition is possible after detection. The difference or latency between stimulus detection (or availability) and the point of recognition may be dependent upon the perceptual load of the observer, the general task requirements at that moment, and the observer's level of concentration on the immediate task. In general, as each of these increases this latency increases and, as a result, the specific point of stimulus recognition can only be predicted under idealized conditions.

Legibility of alphanumeric information is a special case of recognition that has been much studied. For example, the shape and colour of a message are usually recognized at contrast levels much lower than are necessary for the message to be read. (This is the reason for colour and shape coding of sign types.) The letter style, spacing, and contrast of the legend to the sign background are all important in determining legibility of specific sign designs. (For further information on this topic see CIE Technical Committee 4.05 report on Signs.)

Decision Making

A highly significant amount of the air traffic controller task involves decision making and monitoring the effects of those decisions. Three basic kinds of information must be available for an operator to be effective in the decision-making process (Woodson, 1981):

a. Information regarding policies and objectives;

b. Information regarding possible alternatives and consequences; and

c. Information about the current state of the system.

Since the main feedback regarding the behaviour of aircraft is through observation of their symbols on the situation display, decision making for the air traffic controller necessitates additional visual monitoring. Colour coding could provide the visual segregation of targets that must be monitored following decisions.

Visually Guided Responses

Visually guided responses are movements performed under visual control. Almost all intentional movements of the hands, head and eyes are of this type. Since the number of eye and head movements has been associated with fatigue, reducing the number through effective coding procedures may serve to reduce the overall workload upon the worker. To the extent that colour coding can assist in reducing these movements, it may be viewed as a positive feature to any workstation design.

3.5 Ergonomic Considerations

Ergonomic considerations involved in the design of the workstation and the ATC working environment impact the use of colour on video displays. This section discusses some of these issues assuming the availability of (at least moderately stable) colour display technology.

3.5.1 Stimulus to Accommodation

For good vision, a strong stimulus to accommodation must be present on the visual display screen at all times at the point of fixation. In general it is the presence of sharp discontinuities of luminance on the screen (luminance contrast) that provide the stimulus to accommodation. While good quality monochrome monitors are capable of producing sharply defined, high contrast targets, contrast values less than 0.4 can be produced by using sharply defined coloured targets on coloured backgrounds. Depending upon the equipment used, the luminance contrast of virtually any coloured target upon any differently coloured background can be made to be zero. Under such a condition it is still possible to see patterns but the ability to accommodate for the screen distance may be seriously affected. Since the eye is in constant motion when viewing a situation display, variations in the luminance contrast of the retinal image located at the fovea from fixation to fixation may produce a transient loss of the stimulus to accommodation. This has been associated with visual fatigue effects such as headache and eyestrain.

Different colours presented on a colour display are the result of the additive mixture of at least two different phosphors on the screen. Sometimes these phosphors have different decay times (persistence) which can cause problems in reducing the effective stimulus to accommodation.

The use of the chromatic properties of an RGB display can be used to advantage or disadvantage vis-a-vis visual optometric performance, depending upon the choice of figure and background colours. As noted above, various design characteristics of the monitor can potentially reduce any advantage in maintaining a fixed level of accommodation that may be gained by centralizing information into a single screen.

If combined with sufficient luminance contrast, colour coding of symbols should not cause additional visual fatigue per se. For example, using an experimental proof reading task on a high resolution display screen Matthews et al. (1989) and Lovasik et al. (1989) found no evidence of detrimental effects of prolonged viewing of blue or red coloured letters on dark backgrounds. (In these studies the luminance contrast remained high, which probably accounts for the fact that little evidence of fatigue was found).

3.5.2 Display Polarity

The polarity of displays, particularly for text, refers to the use of light characters on dark backgrounds (L/D polarity) or dark characters on light backgrounds (D/L polarity). Each mode has strengths and weaknesses, and since users often have their own preferences, it is difficult to determine whether one is superior to the other.

The advantages of using the D/L display format include:

a. Reflected glare from the display is reduced since the light background masks reflections;

b. Brighter background may enhance visual acuity; and

c. Conventional hard copy documents have the same polarity and difference in luminance contrast when switching back and forth is reduced.

The disadvantages of using the D/L format include:

a. Greater degree of flicker (could be problematic for large format displays);

b. Greater sensitivity to image instability and transient changes in power supply voltage, causing brightness shifts, colour shifts and optical distortions; and

c. Possible shorter display tube operational lifetime.

3.5.3 Lighting

"In areas where the primary function of the lighting installation is to provide illumination for the quick, accurate performance of visual tasks, the task itself is the starting point in the lighting design."

(IES Lighting Handbook, 1972, p. 10-10)

The ATC working environment is subject to a wide range of lighting conditions. Some workstations are located in areas where lighting levels and source points can be controlled. Those stations located in an ATC tower, however, may be subject to conditions varying from steady bright sunlight to near total darkness by night.

Ambient lighting variations are also a problem in maintaining appropriate luminance ratios between the display and the surrounding environment. Although the eye adjusts to varying brightness levels, it does not do so instantaneously. In settings with windows, it is usually recommended that video displays be positioned so that the window is not a background. (Tijerina, 1984).

3.5.4 Glare

The difficult lighting conditions in the ATC work environment also mean a significant potential for glare on the video display. Glare has been defined in two separate, but related ways: disability glare and discomfort glare. Both can contribute to body repositioning and subsequent fatigue for the operator. Disability glare refers to the reduction of contrast of a scene or object seen against a low luminance background due to the presence of a high luminance point source or homogeneous veiling luminance near the centre of gaze (Vos, 1984). Discomfort glare refers to the discomfort experienced by individuals viewing large variations in luminance across a visual field. Visual discomfort can result from glare sources that do not reduce the luminance contrast of objects within the visual field. It is

common to encounter both types of glare, and visual performance, especially on CRT displays, can be adversely affected by both. Boyce (1981) provides a useful discussion of the differences between disability glare and discomfort glare and a number of formulae for computing both.

A number of glare control methods are available, including: orientation of the screen in relation to the source; hoods; etched screens; and various filters. Though glare is not a problem specifically related to colour, solutions used to reduce glare may have some detrimental effects on the colour display. For example, most filters reduce screen luminance and some filters may reduce rather than improve contrast (Tijerina, 1984). The spectral properties of the light are known to affect discomfort glare as well (Ferguson et al., 1953).

3.5.5 Large Screen Viewing Area

According to Transport Canada TP9166E, the common controller workstation (CCWS) "shall have one very high resolution large screen colour display of no less than 20" x 20" useable viewing area, using advanced raster graphics technology."

Colour vision is not homogeneous throughout the field of vision. In fact, most of what is known about colour vision and, indeed, most colour vision tests, concentrate on the central 2 degrees of the visual field (roughly the circle of visual field with a radius of 1 degree of visual angle, centred at the position of gaze). Viewed from a distance of 24," away the large screen display would subtend a visual angle of about 40 degrees from top to bottom and from side to side. Thus, much of the display's contents will be seen in the vision of the near periphery. The colour discrimination properties of the human peripheral visual field are profoundly different from that of the central region. Therefore, any coding schemes that employ colour must take this fact into account. This means that the type of colour coding used may have to be different depending upon where the controller looks most often.

3.5.6 Visually-Derived Fatigue and Prolonged Viewing of Colour Displays

One of the potential advantages of colour coding is its use to increase the efficiency of coding of information within the visual displays at the workstation. Among its many inherent other subtasks, air traffic control requires prolonged viewing of various visual displays. While colour coding might be used to ultimately reduce the visual task load of ATC, it is also possible that through its use a greater density of information will be compressed into a smaller spatial location. If this happens, it is important to consider the impact of colour coding upon ATC information processing efficiency.

Any detrimental effects of attempts to increase information density through colour coding schemes would be expected to appear during episodes of prolonged viewing. However, it has proven to be very difficult to show a causal relationship between prolonged viewing of visual displays and work performance decrements. This is because the relationship between visual performance and both subjective and objective measures of work performance are indirect. While it is generally agreed that video display terminal viewing produces "visual fatigue," there is little evidence to support the association between the role of lighting or the physical parameters of visual stimuli and the incidence of visual fatigue.

Many attempts have been made to quantify visual fatigue using a variety of techniques and theoretical approaches (Lukeish and Moss, 1935; Kunz, 1938; Berens and Sells, 1944, 1950; Simonson and Brozek, 1948; Brozek, Simonson and Keys, 1950; Lowenstein and Lowenfeld, 1951; Colins and Pruen, 1962; Bahill and Stark, 1975; Juris and Velden, 1977; Leibowitz, 1977; Worthey, 1979; Williams, 1982; Craig and Condon, 1984). While the association between visual stimulus properties and prolonged visual performance have been found to be weak in experimental situations, there is evidence that poorly designed visual coding schemes and visual displays can alter the rate and pace of work performance which can be frustrating and stressful. Thus, although visual performance may not be measurably affected by poor display layout and coding design, the worker may suffer from "visually-derived fatigue" -- fatigue due to their indirect effects leading to increased work stress. A very important implication of this is that the behavioral manifestation of visually-derived fatigue would not necessarily be expected to be seen in symptomatology related to vision. Indeed, due to the absolute importance of vision in life, symptoms of reduced visual capacity might be expected to be among the last to appear. Virtually any performance decrement might result from visually-derived fatigue -- from reductions in visual search efficiency on the short term to increased sick leave on the long term.

In the case of the introduction of any technological changes designed to assist in the prosecution of work there is a transient period where the worker must assimilate the changes and accommodate or adapt to them. This typically requires a learning period which, in itself, is an increase on the information processing load of the individual. Such an increase disrupts the pace of work of an individual. With the disruption of the work pace in time-constrained jobs, typically comes either increases in occupational stress levels, decreases in work performance, or both. Since tolerance for decreased work performance in the ATC occupation is low, occupational stress would be expected to rise with the introduction of colour coding. The rate at which it decreases will depend upon the rate at which the ATC personnel who use the new coding schemes can assimilate them into their work. While it seems evident that a good scheme should be assimilated faster than a poor one, there is no evidence available to support this notion. Thus, any attempt at evaluating the ultimate success of a colour coding scheme should take into account both the transient factors (that is, the ease with which the ATC can acquire use of the coding scheme and integrate it into his/her job) and the steady-state factors (that is the degree to which the colour coding scheme increases the system performance).

It is important to note that the value of given colour coding scheme with respect to the steady-state concerns may not be predictable from the information obtained regarding the transient performance variables, such as ease of learning, etc. While "colour continues to be universally welcomed," little direct evidence exists of its value in either the transient or the steady-state situations noted above.

3.5.7 Potential Colour Coding Problems

For observers with normal colour vision:

Effective colour coding of symbols, characters, lines or areas can only be achieved with careful attention to the controller's need for various types of information and by keeping in mind the well-known difficulties in learning arbitrary coding schemes. Where possible, designers should try to take advantage of prior learning so that colour codes are as consistent as possible with prior experience.

It may, for example, take longer to perform some tasks because of the need to ignore colour coded information.

For observers with abnormal colour vision:

As colour vision deficiencies are, for the most part, sex-linked recessive inherited disorders, there is a small but significant proportion of the male population who are missing at least one of the retinal photopigments required to enjoy normal colour vision. If colour coding is adopted for Canadian ATC workstations, this fact will have important implications for personnel selection and operational staff monitoring procedures.

4.0 ATC TASKS AND DISPLAYS

4.1 Role of the Controller

Few vocations entail as much responsibility and fewer still ask more of its practitioners than the job of the air traffic controller. Cursory observation of controllers at work reveals individuals sitting at electronic workstations and doing various tasks such as watching video screens, reading, writing, talking, typing and using the telephone. There appear to be times during the shift when the controller is apparently doing little while, at other times, the work pace can be frenetic.

As with any job, the air traffic controller's job can be viewed as a set of activities, consisting of small tasks and still smaller subtasks, which, when integrated, form the primary source of control for the air traffic control system. These activities require:

a. Processing information about the status of aircraft and weather within a given sector of airspace;

b. Making decisions regarding future actions affecting the positions of these same aircraft through reference to the aircraft status and through knowledge of the air traffic system's operational rules; and

c. Communicating these decisions to other personnel in the system--both in the air and on the ground.

While both perception and communication produce observable behaviour, a significant amount of the work that the controller performs during the course of a shift is cognitive in nature: decision making, problem solving, recall of operational rules, assembling appropriate operational commands and mentally sequencing sets of these commands so as to optimize traffic flow, while maintaining aircraft separation.

Cursory observation, such as noted above, can only provide a hint of the real job of the controller because, while the individual may not appear to be physically active at a particular moment, he/she may be engaged in a variety of cognitive tasks. In busy traffic situations, the controller must often perform command, control and communication tasks which appear to be carried out concurrently.

The appearance of concurrency is an illusion. Ample psychological research has shown that at a given instant, only one task is actually being performed. The appearance of concurrency is maintained by the neuropsychological equivalent of multiplexing or switching of the various tasks. Task switching requires significant mental effort and, as such, it requires a certain amount of the ATC's cognitive and attentional capacity before and during the switching procedure. All other things being equal, occupations where there is a requirement to switch among several "concurrent" tasks have greater total workloads than occupations where there is no such requirement. By adding to the workload, task switching also contributes to work-related fatigue and stress.

It is evident that controllers who are efficient at their work have developed strategies for optimizing task switching. This requires that the controller be able to think forward in time so as to order the tasks that will make possible efficient control of aircraft in the near future as well as the present.

In our view, an important goal regarding recommendations for the use of colour in ATC displays is, to optimize task switching through the use of colour coding. This includes the conditions where colour might be used to advantage to provide information to the controller that would lead to more efficient task switching procedures.

4.2 ATC Task Descriptions

The challenge in development of ATC systems is to build interactive real-time control and decision support systems which can augment the problem-solving and decision-making capabilities of users. The kind of support that is built into these systems has become crucial. Without the appropriate functionality, even the most advanced user interface will fail. The starting point in system design is the controller and the controller's interaction with the system.

Task decomposition and analysis has been performed for air traffic controllers on several occasions. A recent effort for certain positions in the American ATC system is documented in DOT/FAA/AP-87-01, FAA Air Traffic Control Operations Concepts. The operational activities, sub-activities and tasks identified in this document were compared to and modified for the CAATS system by the project team. The results are contained in Appendix C.

In the task decomposition presented in Appendix C, operator tasks are categorized as being a combination of one or more of four types:

a.	Entry:	Entry of data into the system;
b.	Receipt:	Receipt of information through displays and direct observation, but excluding voice communications;
c.	Analysis:	Cognitive assessment and evaluation of data, involving no input or output of information unless combined with another task type; and
d.	Verbal Communication:	Transfer or exchange of information with another person via telecommunications, radio, or directly.

Each of these task types requires performance of some or all of the visual functions described in Section 3.4.3. Entry of data into the system requires visual attention, recognition and visually guided response. Receipt requires visual attention, detection, recognition and visually guided response. Analysis requires visual recognition and decision-making. Verbal communication is a variation on the Entry and Receipt task types. Though the impetus for verbal communication may depend on some visual function, it can be assumed that it is adequately covered under the other task types, so that it need not be considered for application of colour.

4.3 Presentation of ATC Information

The task decomposition performed in Appendix C refers to information sources for all applicable subtasks. The information sources of interest to application of colour are those that are communicated

through the display. This section provides general descriptions of the displays that have been identified by the Operational Performance Requirements for incorporation into CAATS. These displays are of three main types:

a. Messages and Command Feedback;

b. Tabular Displays; and

c. Situation or Graphical Displays.

4.3.1 Messages and Command Feedback

There are a number of areas where the CAATS system must provide capabilities in displaying messages, prompts or command feedback. In some cases, interaction with the user through text editing capability or interface dialogue is required.

Messages

There are a large number of message functions of varying importance that the CAATS must perform. These include:

a. Alert and warning messages;

b. Error messages;

c. Mail messages; and

d. Help facility.

A critical aspect of CAATS functionality is its display of alert messages. Alerts are required in a number of areas, including conflict detection and prediction, minimum safe altitudes, airspace related requirements, or degradation of system performance. Alerts are usually time or event driven. Because of this, the display method used must ensure that the attention of the controller is drawn to the message. The display method should also be limited only to alert messages so that its effectiveness is not reduced by overuse.

Warning messages are related to alert messages, but are of lower urgency. They may be used in situations such as when system utilization is approaching a certain level or when a duplicate flight plan is detected by the system. The display method used for warning messages should not allow it to be confused with an alert message, thereby ensuring the effectiveness of the alert method.

Error messages usually are the results of an input validation process by the system. The CAATS system requires that all input errors be reported in detail. Error messages should be consistent in their response and application in the system.

The CAATS is to provide an ATC mail system for routing messages to other workstations. The mail system will require text editing capabilities and methods to indicate that a message is incoming.

Context sensitive help information must be available to the workstations in CAATS. Usually the help function will be invoked by the controller. Help information will likely be displayed in a textual format.

Command Feedback

Command feedback is generally presented in association with the "command line" where users enter commands to the system with the keyboard, function keys, or other input devices. Feedback may include prompts or messages when commands are incomplete or out of range.

4.3.2 Tabular Displays

The controller needs to be able to manage lists of information. For CAATS, these lists are presented primarily in tabular displays. The controller will be provided with the capability to edit these lists by reducing or expanding the information displayed, sorting and moving list entries and suppressing unnecessary entries. The controller will also be able to modify data in most lists to reflect changes in the traffic picture.

Flight Data Display

The Flight Data Display presents controllers with flight data entry information arranged into lists (e.g., fix posting lists), and with a flight data readout area. Each posting list is presented as a separate view so that the controller can set attributes such as sort factor and sort order for each view. Flight data entries (FDEs) reflect the current state of the flight data and are updated automatically by the system. Controllers can make changes to the data in the FDEs.

Special Lists

CAATS will contain several lists of information in a concise and compact manner for quick scanning by the controller. These lists include the following:

a. Weather Elements;

b. System Time;

c. Hold List;

d. Inbound List; and

e. Arrival List.

Each list is to be independently displayed, suppressed and sized on controller command. Selected data items for each list may be emphasized or highlighted for either an adapted time period or until the controller deselects the emphasis.

4.3.3 Situation and Graphics Displays

The Situation Display contains the plan view of a geographic area including target and track data, symbology and weather. The geographic area is defined by a centre location and a range about that location. Map data is presented on the Situation Display. The controller can select the groups of map data desired for display. The controller can vary the brightness of map data groups by changing the brightness level of brightness control groups. Special use airspace boundaries can be suppressed and displayed.

Due to the event driven nature of the ATC environment, the controller will be provided with capabilities to manage the Situation Display. In addition, the controller will be able to perform basic ATC operations on track data and symbology in the geographic area that is being displayed on a Situation Display (e.g., initiate and accept handoffs). The controller will also be able to:

a. See more or less of a geographic area by changing the range and offset;

b. Annotate the Situation Display to assist operational activities;

c. Manipulate the track data and symbology to facilitate monitoring and to evaluate aircraft separation; and

d. Use the track data and symbology to perform basic ATC operations.

4.3.4 Windowing

The CAATS will provide a windowing capability to controllers so that they may view items such as situation displays and tabular lists at the same time. A window is an area on a computer display, usually rectangular and limited by borders, that contains a particular view of some data in the system. Windows may indicate separate processing activities, or different data from the same processing or static database.

The concept of windowing is attractive because it is similar to the way people actually work. In managing and assimilating information, people often monitor, categorize and manipulate information from several sources. When using paper, they may categorize these sources into reference piles and keep opening pages from the different piles as they work. Windowing can provide a similar concept electronically.

In an application such as ATC, it is important for safety and efficiency reasons that the design for the presentation and the rules for the movement and resizing of windows be carefully considered. For windows occupying the same display the allocation of display space is important. Windows may be "tiled," in which case they share borders but do not overlay each other. When a tiled window is

resized, adjacent windows must automatically be resized. Alternatively, windows may "overlay" each other. Usually an overlaid window will block information in the window behind it.

4.4 CAATS Operational Performance Requirements

The CAATS Operational Performance Requirements (OPRs) (TP9166E) provides a detailed explanation of the operational requirements for the CAATS system. This document was reviewed to identify the areas which might be affected by the use of colour on the workstation displays, or those that could have application for colour use. These areas relate mainly to the displays described in Section 4.3. The implications of colour in these displays or the man machine interface are discussed in this section.

Appendix D contains Table 2.12-1 Display Requirements from TP9166E. This table indicates which workstations in the CAATS system require the listed display items. Since we are interested primarily in real-time controller tasks, we will consider only the CCWS and the CTWS requirements.

4.4.1 Alphanumerics

As indicated in TP9166E, alphanumeric characters will be used to display the various messages and lists that are described in Sections 4.3.1 and 4.3.2. In some cases, such as within the ATC mail system, text editing capabilities will be required.

There are a number of issues in presenting text on a display including upper and lower case usage, spacing between words, logical groupings and font sizes. The CAATS OPRs do not define particular requirements within each of these issues, but refer the detailed design of displays to the man machine interface program (MMIP). Some of these issues that may be affected by colour use are discussed below in relation to the OPRs.

Alert and Warning Messages

The alert messages in the CAATS system are displayed for urgent situations that occur infrequently. The general categories of alerts specified for the Control Tower Data Processing Systems (CTDPS) are (OPR 3.4.1):

a. Aircraft emergencies;

b. Aeronautical and meteorological alerts; and

c. Outages of essential equipment such as computers and radio channels and their return to service.

In all cases, the controller is to have the capability of suppressing the alert once it has been acknowledged. The OPR also states that "alert data for an aircraft presented at multiple workstations shall be identical at all workstations." This implies that any coding methods used for alerts, colour or otherwise, will not be modifiable by the individual controller.

Colour may be used as a highlighting technique to emphasize the urgency of the message or to draw attention to the message. Because of the criticality of the controller recognizing the message as an alert, an additional coding method should be considered. Flashing is known to be an effective attention-getting highlighting technique that could be used in conjunction with colour. Flashing that alternates between lower and higher brightness might be suitable for alert messages, since the urgent information is never removed entirely from the display. The use of such a redundant coding technique also provides insurance that the alert will be recognized if for some reason the colour is not functional.

If colour coding is used for alerts, the colour used should be consistent and not used for other coding requirements. This protects the effectiveness of the coding. An obvious colour choice for alerts is red, because of its connotations of emergency or danger situations to most people.

Warning messages should not be coded using the same methods as alerts so that the effectiveness of alerts is not compromised. Using a desaturated or less intense red is not recommended since the distinction may not be recognized by the user if the alert red is not available for comparison.

Tabular Displays

The CAATS requires a number of tabular displays and lists. The most important of these, in terms of functionality of the system, are the flight plan and data displays for the CCWS and the CTWS.

The effectiveness of the flight data tabular displays are affected by the visual grouping and layout of the data. A number of studies have been performed concerning grouping techniques and their effects on user performance. A general recommendation is that the 5 degree visual angle to which the eye is most sensitive (corresponding to the foveal region of the retina) can be used to define areas for presentation of information. For a typical 80 character width display, a 5 degree circle corresponds to an area approximately 12 to 14 characters wide and 6 or 7 lines high (Tullis, 1988). Screens with groups no larger than 5 degrees seem to be scanned more efficiently than those with larger groups.

Assuming that similar grouping techniques are used for the flight data displays in CAATS, colour may be used to code a whole group containing a subset of the information contained in Table 3-1 of the OPRs (OPR 3.4.1) corresponding to one ACID.

David (1984a) has suggested that coloured backgrounds (as opposed to light letters on dark backgrounds) may be preferable, providing that definition of the characters is maintained. He states that "where a tabular display uses coloured backgrounds, it tends to appear less cluttered than a monochrome display." If this method is used for tabular displays, desaturated background colours should be used and sufficient chromatic difference should be maintained, as discussed in Section 3.3.4.

Colour may also be used to code different elements within one information group. The ACID might be coded in different colours to indicate outbound or inbound aircraft. This may be acceptable as long as codes are consistent and not too many colours are used.

OPR 2.4.6 requires that "the FDPS shall highlight displayed flight data, at appropriate workstations, to indicate that a hand-off:

a. has been initiated;

b. has been completed; and

c. is being delayed."

Colour can be used to indicate these three states, perhaps with desaturated coloured backgrounds, but these colour codes must not be confused with or affect any other colours being used. This example shows that trade-offs must be made that will likely restrict the use of colour to the most appropriate applications in terms of benefiting controller tasking.

A number of functions in the OPRs require that changed or updated data be displayed and highlighted (e.g. OPRs 2.8.4, 2.13.1). This again is a potential application for colour, but the colour code used must not be confused with other applications. The FAA system, for example, uses white to indicate that text has been changed or updated (the nominal text colour used is green). This implies that white may not be used for text display for any other reason, once the controller has learned that white indicates change.

4.4.2 Graphics

Information concerning the use of colour on graphics displays is not as available as that for alphanumerics. Graphics tend to be complex and various. The effectiveness of different techniques tends to be very dependent on the nature of the task and the data being presented.

Situation Displays

The CAATS system will employ extensive graphics displays. The most important of these is the situation display which presents the plan view of a geographic area with associated data and symbols describing flight data conditions.

The situation displays use a set of four sector-specific primary maps with three additional levels of map data. These levels may be displayed selectively or cumulatively (OPR 2.4.32). The operator will have extensive control over these maps, including the following:

"3. Map Characteristics ...

5. it shall be possible to pan and scroll the map;
6. it shall be possible to change range/scale smoothly and continuously (zoom); and
7. the map symbol size shall change through at least four sizes as the map scale changes."

(OPR 2.4.32, 3., 5-7)

The variations of symbol size have implications for use of colour. It may be difficult for controllers to recognize the colour of symbols that are colour coded and have become too small. This problem, caused by the characteristics of the human visual system, may be compounded by the display technology. If misregistration or blooming effects are present on the display, colours as well as legibility of small symbols may be additionally affected.

The position entry device (PED) will provide a dynamic interface between the controller and the situation display. The PED position will be indicated on the display by a special symbol which may vary depending on the user and a specific operational situation. (OPR 2.12.1, 6., c.) The possible symbols will have to be carefully designed to maintain colour and legibility on different display screens. Because this symbol can be moved to any position on the situation display, it may be laid on top of different objects or text of different colours. The controller must be able to easily locate this symbol so that the chromatic difference between it and any possible background must be sufficient. David (1984a) has recommended that no more than four colours be used on plan views. This chromatic difference requirement may further limit the possible number of colours that may be used on the situation display.

The symbol size of the PED indicator may also be a concern. There will likely be a trade-off between position accuracy and symbol visibility, especially since it will be possible to zoom the display. The symbol must be of sufficient size and appropriate design to ensure integrity of colour in display configurations.

Smith and Mosier (1986) consider that area coding using texture or colour may be appropriate for maps and situation displays. They also recommend considering use of tonal codes (different shades of one colour) where users must make relative judgements for different coloured areas on a display. This may be appropriate on the situation display to indicate severity of weather conditions or similar varying conditions.

Static Graphic Displays

The CAATS system must also provide secondary maps (e.g. aeronautical maps) which will typically be used as reference information (OPR 2.4.32, 2.). These maps will likely not display dynamic flight information, but will still have the pan, scroll, zoom and scale capabilities of the situation displays (OPR 2.4.32, 3.). Therefore, the considerations described above will also apply.

Icons

Besides the PED indicator discussed above, other symbols or icons are to be designed for and included in CAATS. Such icons may occur in display annotation on flight strips (OPR 2.4.31) as well as aircraft position symbols for radar and non radar-tracked targets (OPR 2.12.1) or the annotations on Approval Requests (APREQs) received by the Altitude Reservation Unit (ARU) (OPR 4.2).

The coding of icons requires special consideration. Icons should be designed to look like symbols that the controller population already uses or is familiar with. Because icons are not as well recognized as alphanumerics, they must be large enough to avoid misinterpretation or confusion with other

symbols. It becomes especially important to ensure that the use of coding techniques, such as colour or reverse video, do not interfere with the legibility of these symbols.

4.4.3 Logical Display Layout

The OPRs state that "the CCWS display shall be capable of being windowed into functional display areas. The FDPS shall provide for a site-adapted default database to construct the display composition at initial operator log-on, or on request. The default condition shall be independently specifiable for each display" (OPR 2.12.1, 5.). Tiled or overlaid windows are not specified and it is assumed that their use will be determined by the MMIP.

Though windows provide the controller with a very flexible environment, allowing tailoring of the display according to current conditions, a number of issues must be considered in their design. Overlaid windows may block critical information on another window, or prevent the controller from recognizing that a change in status has occurred.

As a minimum, the following characteristics should be considered for each specific window and for combinations of windows in the design process:

a. Appropriate prompts associated with a window; e.g., Appropriate "more" indicators, number of lines or entries, and criticality or attention indicators;

b. Mandatory or optional display of a given window; e.g., It may be desirable to force the display of a message window and not the window containing a hold list. The contents of each selected window must be examined individually within the environment that it will be used in;

c. Minimum and maximum size of any window; e.g., It may be operationally desirable to restrict the minimum size of a window to ensure the display of a minimum set of useable data within the window; and

d. Ability to overlay a window on top of another; e.g., It may be desirable to have the capability to overlay a window on the situation display but not a window containing flight progress textual data.

Some consideration has been given by ATC designers to using transparent windows for overlays so that background window information is not hidden from view. There is the danger that alphanumerics will be laid on top of other alphanumerics so that neither window can be read. If this design is restricted to overlaying alphanumerics on area coding in situation displays, consideration must be given to colour difference between background and foreground and ensuring character legibility.

Users typically have control over the size of windows (OPR 2.12.1, c.). This control may need to be restricted in the ATC environment to protect the size of alphanumerics as discussed in Section 5.1.1, and to ensure that all critical information in a window is displayed.

5.0 GUIDELINES FOR USE OF COLOUR

Guidelines for use in design of ATC displays are developed in this section, based on the background material presented in the previous sections.

5.1 Application of Colour

When used in specific ways, colour has been shown to be effective as an alerting technique, to improve visual searching activities and to be useful in grouping of data (Christ, 1975). Other studies, however, have shown that colour can be distracting and detrimental to performance when not used carefully (Luria, 1986). Simply adding colour to a screen will not guarantee an improved system or improved performance. Colours are subject to contextual effects, and deciding their proper use can be complex. The size of a coloured image, the colour of images adjacent to it, and the ambient illumination all exert an influence on what the operator perceives.

Our objective in this work is to investigate and provide guidelines for the most effective ways of using colour and to warn against possible poor usages. A number of areas must be examined in relation to colour in screen design, and in the functions for which colour can be used. Each of these areas is discussed in the following sections.

5.1.1 Design Considerations

As already seen, the human eye and brain have specialized mechanisms for receiving and interpreting colour stimuli. These factors must be kept in mind when designing for the use of colour on video displays. The design considerations involved are discussed in this section.

Colour Specification

Different functional tasks using colour require different considerations for specification of colours to use. These tasks may require colour discrimination, symbol legibility, or colour identification in isolation.

For tasks where discrimination in colour is required, the CIELUV equation discussed in Appendix B may be used to maximize the perceptual differences among colours. The $\Delta E_{Y_{u'v'}}$ measure can be used to design for symbol legibility, as discussed in Appendix B. When colours must be identified in isolation from each other, no good measure has yet been determined (SAE, 1988). The CIELUV equation may be used as a starting point for this application.

Galitz has recommended a number of guidelines when selecting colours for different information. Examples include the following (Galitz, 1989):

a. Use contrasting colours (e.g., red/green or blue/yellow) to emphasize separation of information;

b. Use colours associated with longer wavelengths to indicate the necessity of action (red, orange, yellow);

c. Use blue or yellow in the operator's peripheral vision since these colours are best seen in the periphery; and

d. Always be consistent in the use and meaning of colours within the same screen and throughout the screens in an application.

These guidelines may be useful at a preliminary stage, but most sources warn against the use of the extreme short or long wavelength colours (blue or red) which Galitz (1989) has included here (Kinney, 1978; Snyder, 1988). Because these colours are not equally focused by the cornea and lens, the simultaneous presentation of both blue and red may produce a false indication of depth, where red appears closer than blue. The effect is seen to a lesser extent with blue and green or red and green on a dark background.

Number of Colours

In Appendix B it is found that most CRTs would be able to supply 7 to 10 simultaneous colours if the CIELUV equation was used to maximize perceptual spacing. The literature varies in recommending the number of colours that should be used on a screen at one time. The SAE guidelines state that the use of more than six colours may degrade search, identification and coding tasks (SAE, 1989). Kinney and Culhane (1978) reduce the number of colours to a recommended maximum of 3 or 4 colours based on reports of reduced information processing capability with more colours, and because the colour vision characteristics of the ATC population are not well-known. Smith and Mosier (1986) state that while 11 colours may be reliably distinguished, it is safer to use no more than 5 colours in practical applications.

Luminance and Brightness

In general, increases in the average luminance of a display result in improved visual sensitivity. Relatively small improvement is found beyond 35 cd/m^2 however (Snyder, 1988). Where colour discrimination is required, a neutral background colour with intermediate luminance may be preferable to a completely dark or light background. The SAE guidelines recommend that the symbol to background luminance contrast ratio should not exceed 50:1.

Evidence suggests that increased luminance contrast results in an increase in symbol legibility, but in a decrease in the ability to discriminate colour. The SAE guidelines suggest that a balance can be achieved with a symbol to background luminance contrast ratio of 20:1. This area needs to be further explored for different colour combinations.

The optimum settings of luminance for foreground and background colours is affected by the environment in which the system must operate. For example, in low ambient illumination conditions, symbols on a display may be perceived to float, so that increasing the background luminance in relation to the symbol will help to fix the symbols on the screen. This increase should not be higher than the symbol luminance so as not to interfere with the user's dark adaptation.

Contrast and Legibility

Luminance is the most effective factor for controlling contrast between foreground and background areas or information, and thus affecting legibility of symbols. The use of contrasting colour (as opposed to manipulation of luminance) can contribute to separation of information and screen areas.

However, there are specific combinations of colour for which no effective luminance contrast appears. These combinations will not give rise to figure ground segregation since no border appears between the target and its background (Tansley and Boynton, 1978). A vision model that predicts how distinct a visual border will be formed between a figure and a background, each of different colours, is found in Valberg and Tansley (1977).

Control of Brightness/Contrast

Individuals have individual preferences for levels of brightness and contrast ratios between symbols and background colours. For this reason, it may be desirable to have manual brightness and contrast controls available for adjustment by the user.

Some brightness and contrast characteristics can be controlled automatically, depending on ambient lighting levels. To provide an automatic compensation system, the SAE recommended three types of brightness control for electronic aircraft displays:

a. A manual brightness control to accommodate individual differences in visual sensitivity;

b. An automatic brightness/contrast compensation function that changes the display luminance as a function of changing ambient light levels incident on the display (as detected by an internal light sensor integral to each display); and

c. An automatic brightness/contrast compensation function that changes the display symbol-to-background contrast as a function of changing luminance the user's forward field of view (detected by a forward facing light sensor) (SAE, 1989).

Symbol Size

As symbol size becomes smaller, colours become increasingly difficult to distinguish from one another. Such visual acuity measures are often expressed as the angle subtended at the nodal point of the eye by the object in view. It can also be expressed as the reciprocal value of the visual angle in minutes of arc (which increases as acuity increases).

Colour coding of symbols less than 20 minutes becomes problematic because of the lack of short wavelength sensitive cones in the central fovea (Boynton, 1979). For example, blue and yellow are difficult to distinguish below 30 arc minutes (approximately 6.9 mm at a distance of 762 mm) of visual angle and red and green are difficult to distinguish below 15 arc minutes (approximately 3.4 mm at a distance of 762 mm) (SAE, 1989). Therefore, the size of the symbol affects the useful colour gamut.

The type of information being displayed also impacts the suitability of symbol size. The main concern discussed above is with characters being too small to read. When large amounts of text are presented on the screen, Snyder (1988) recommends symbol sizes of 20 to 22 arc minutes, and none in excess of 24 arc minutes. It is felt that larger characters reduce reading efficiency because they require more eye movements per lines of text.

The symbol sizes above indicate only the symbol height. In general, the height to width ratio for alphanumeric characters should be between 1:0.7 and 1:0.9 (Snyder, 1988; Tijerina, 1984).

Different Screens or Screen Series

The use of colour on different screens in the same application must be consistent to be effective in helping the user. This is in agreement with recommendations for consistent coding across displays in an application (Smith, 1986).

David (1984a) comments that it is not always necessary for plan view and strip displays to have correlated use of colour. In the case where colour is used to indicate direction of flight on flight strip displays, he considers using colour for the same purpose on situation displays to be redundant and warns that it might even be confusing.

5.1.2 Functional Uses for Colour

The functional areas in which colour has potential uses are discussed here in a general manner. The areas included are those that were most commonly mentioned in the reviewed information sources.

Alerting the Operator

The use of certain colours can have an immediate effect of getting or focusing an operator's attention. This can be useful when a condition arises in which the system must alert the operator. This alerting impact is only effective when the specific colour is used consistently and rarely. Colours used in this context should correspond to their usually accepted meanings, for example:

RED	-	Stop or Dangerous Situation
YELLOW	-	Caution
GREEN	-	Go or Normal Situation

As was discussed in Section 3.3.4, stimuli generally should be more intense when they occur on the periphery of the visual field. The use of redundant coding techniques might be indicated in this case if the colour red is being used in an alerting function. For example, a wink or blink coding combined with red colour coding may significantly enhance the alerting potential of a stimulus in the periphery. Redundancy is also useful in critical information display for people with colour deficiencies, or in the case when the integrity of the colour display itself is degraded.

Organizing Information

Colour has been shown to be effective in organizing and differentiating between logical groupings of information or data. In this way, it may be used as a formatting aid in structuring a screen. For this purpose, most sources recommend that the number of colours used be restricted since too many colours may actually be counter productive in organizing information.

The use of colour for organization of information differs from the coding function in a subtle way. Referring to this organization function as "lay-out," Vroemen (1986) states "It seems that colour as a lay-out facility has effects which are mainly related to cognitive behaviour like understanding and recognizing the logical structure of the display, and on non-voluntary behaviour like attention".

Searching or Scanning

Colour is generally thought to be superior to other methods in search tasks because it is well detected in the parafoveal and more peripheral parts of the visual field (de Weert, 1987). Kinney and Culhane (1978) argue that some colours, specifically red and green, are not as well detected in the peripheral areas based on the mapping of retinal colour sensitivity areas discussed in Section 3.3.4.

One explanation of the search superiority is provided by Treisman (1982). Her theory considers two separate information processing systems. The first is an automatic, preattentive system that works in parallel and forms maps of different visual features. The second is a non-automatic, attentive system that works serially and combines outcomes of a number of the "feature maps" resulting from the first automatic system. It is postulated that colour detection is in the automatic system and that form recognition in the serial system. This results in faster search results from colour than from form.

Coding

Colour may be used effectively in grouping or colour coding categories of information on a display. Selecting these categories and their corresponding colours effectively requires a definite understanding of how the information is to be used. Colour coding is particularly effective for qualitative information (SAE, 1989).

The method of using redundancy in coding is also effective in the transfer of information to the user. In redundant coding, one form of coding is combined with another coding scheme. If for example the colour code is not used, the other coding scheme(s) still identify the different categories. Redundancy can be useful for operators who have some degree of colour deficiency or in situations where ambient lighting or other display conditions affect the operator's colour perception.

5.2 Advantages and Disadvantages of Colour Coding

The following list summarizes how colour may assist in the coding of information on the visual displays of air traffic controllers.

General Advantages of Colour Coding Information in ATC Displays

For objects and small icons:

a. Some increased speed of recognition and visual segregation of objects by visual search in paracentral field of view.

b. Superior recognition and visual segregation of tabulated items in alphanumeric displays.

c. Perceptual grouping of like-coloured items in a random display.

d. Useful for assisting in attention getting under restricted conditions.

e. Useful for correlation of screen objects with non-screen objects (e.g., keys or switches).

For backgrounds:

a. Solid background for visual segregation of tiled, overlapped areas.

b. Perceptual grouping across displays of related information.

c. As solid background colour for common classification of alphanumeric information on tabular displays.

d. Outline identification for special purposes (accompanied by blinks or reverse video).

For graphics:

a. For pseudocolour mapping (coding along a logical continuum; e.g., air pressure or wind speed).

b. For delineation of restricted sets of graphical features on Plan View displays.

c. Superior means of providing low contrast overlay or underlay over which other information is to be presented since low luminance contrast is more difficult for accommodation.

General:

a. Probably more aesthetically pleasing (at least in the short term).

b. May reduce appearance of visual clutter if coding schemes were efficiently designed.

c. May permit reductions in display brightness to increase CRT life.

d. Potential to positively interact with other coding schemes to provide greater redundancy.

e. Can be linked to other properties of objects to make them more memorable.

General Disadvantages of Colour Coding Information in ATC Displays

For objects and small icons:

a. Coloured objects and icons must meet minimum size requirements that are generally larger than monochrome objects/icons.

b. Possible negative interaction with display hardware if registration is not maintained to criterion.

c. Limited number of useable colours (probably less than 5).

d. Visual search is not improved if the colour coding of items must be ignored in order to perform the search.

e. The alphabet size is small for colour coding.

For backgrounds:

a. Desaturated colours necessary in order to prevent misregistration problems in alphanumeric overlays.

b. Colour coding between or among several displays will require some calibration to ensure the same colour is reproduced within some level of tolerance across equipment.

For graphics:

a. No generally agreed upon coding scheme for pseudocolour mapping.

b. Possible confusion when combining colour graphics with coloured backgrounds on the same visual display unit.

General:

a. Individual controllers will probably not have optional adjustments or colour choices.

b. Limited signal alphabet (i.e., range of useful colours) will restrict utility in any given domain.

c. Colour vision will have to be more strictly regulated in ATC population (by how much will depend upon the schemes chosen).

d. Hardware calibration and maintenance is more difficult and time consuming.

e. Potential source of complaint from ATC personnel.

f. Colour coding involves the arbitrary assignment of colour to other objects.

5.3 Guidelines

Guidelines organized according to the design considerations discussed above are presented in Table 1. This table also references the basic controller functions and related OPRs to each of the guidelines.

TABLE 1: COLOUR USE GUIDELINES

Design Consideration	Guidelines	Related ATC Functions	Related OPRs
Colour Specification	• Addition of colour to the display should enhance operator performance.	All functions	1.2 Scope
	• Where colour discrimination is required, the CIELUV equation should be used to maximize perceptual differences among colours.	Receipt Analysis	2.2.2 Adapted/Dynamic Data 2.4.6 Transfer of Jurisdiction 2.4.7 Pointout 2.4.22 Graphic Delineation Capabilities 2.6.3 Flight Plan Processing 2.7.1 Position Reports 2.13.1 Automatic Flight Strip Output 2.15.2 Strip Format Creation 3.4.1 Displayed Data 4.2 Altitude Reservation Evaluation
	• Where symbol legibility is required, the $\Delta E_{u'v'}$ legibility equation should be applied to maximize reading response performance.	All functions	2.4.6 Transfer of Jurisdiction 2.12.1 Common Controller Workstation 3.4.1 Displayed Data
	• Use colours consistent with typically accepted meanings.	All functions	2.7.4 Clearances and Instructions 2.12.1 Common Controller Workstation 2.15.2 Strip Format Creation 3.4.1 Displayed Data
	• Avoid the use of narrow-band wavelength colours, and of colours at the extremes of the visual spectrum.	All functions	All OPRs related to displays.
	• Consider that red and green are best viewed in the centre of the field of vision. The eye perceives blue and yellow in the periphery better than red and green.	All functions	All OPRs related to windowing, including: 2.1.10 Aeronautical Data 2.4.32 Maps 2.12.1 Common Controller Workstation
	• Where possible, colour specification should be based on actual tests of the system under actual or simulated operational conditions.	All functions	All OPRs.
	• Colour specification for alert conditions should generally agree with typical conventions such as use of red. A highly saturated red is probably not the most suitable colour, and an orange/red colour should be used. These colours should be reserved only for the alerting function, since their use elsewhere will degrade the value of the alert colour coding.	Receipt Analysis	All OPRs related to alerts, including: 2.3.2 System Performance Modelling 2.5.1 Aircraft States 2.7.4 Clearances and Instructions 2.7.5 Conflict Detection 2.7.6 Conflict Prediction 2.7.9 Altitudes 2.8.3 Airspace Related Requirements 2.8.4 Flight Environment Changes 3.4.1 Data Display

Design Consideration	Guidelines	Related ATC Functions	Related OPRs
	• Where users are to make relative judgements for different coloured areas of a graphic display, such as weather maps, use of tonal codes (different shades of one colour) may be considered.	Analysis	2.4.24 Preview Area 2.4.28 NOTAM and Weather Message Code 2.4.32 Maps 2.10.2 Weather Data 2.12.1 Common Controller Workstation 3.4.1 Displayed Data
Number of Colours	• The number of colours used should be kept to a minimum so that performance is still enhanced by its application. More than 6 simultaneous colours is thought to detract from performance.	All functions	All OPRs related to displays.
	• The number of colours used is limited by the colour generation capability of the display, and by the application of minimum colour spacing through the CIELUV equation.	All functions	All OPRs related to displays.
	• Under high ambient lighting conditions, discriminability of colours may be reduced, so that the number of simultaneous colours may also have to be reduced.	All functions	3.2.1 Control Tower Workstation
	• No more than six colours should be used on a screen at one time where organization and lay-out of information is being enhanced by the addition of colour.	Receipt Analysis	All OPRs related to displays, particularly tabular displays, including: 2.6.2 General Flight Planning 2.12.1 Common Controller Workstation
	• To protect the effectiveness of the alert coding, only one colour should be used for alert indication.	Receipt Analysis	All OPRs related to alerts, including: 2.3.2 System Performance Modelling 2.5.1 Aircraft States 2.7.4 Clearances and Instructions 2.7.5 Conflict Detector 2.7.6 Conflict Prediction 2.7.9 Altitudes 2.8.3 Airspace Related Requirements 2.8.4 Flight Environment Changes 3.4.1 Data Display
Luminance and Brightness	• Differences in the brightnesses of display colours may be used to accentuate the differences between colours.	All functions	All OPRs where colour may be used as a highlighting technique, including: 2.2.2 Adapted/Dynamic Data 2.4.6 Transfer of Jurisdiction 2.4.7 Pointout 2.4.22 Graphic Delineation Capabilities 2.6.3 Flight Plan Processing 2.7.1 Position Reports 2.13.1 Automatic Flight Strip Output 2.15.2 Strip Format Creation 3.4.1 Displayed Data 4.2 Altitude Reservation Evaluation

Design Consideration	Guidelines	Related ATC Functions	Related OPRs
	• Ambient lighting conditions affect appropriate luminance settings. Typically, the average display luminance to remote light surfaces should be 1:10.	All functions	3.2.1 Control Tower Workstation
Contrast and Legibility	• Where colour discrimination is required, the symbol to background luminance contrast ratio should not exceed 50:1. To balance the trade-off between symbol legibility and colour discriminability with increased luminance, a symbol to background luminance contrast ratio of 20:1 may be appropriate.	All functions	All OPRs related to displays.
	• Narrow-band wavelength blue colours with short dominant wavelengths should not be used for detailed alphanumerics or symbols.	All functions, particularly for tabular displays	All OPRS, particularly those related to tabular displays, including: 2.6.2 General Flight Planning 2.12.1 Common Controller Workstation
	• Use desaturated colours for areas or backgrounds.	All functions	All OPRs related to displays.
Symbol Size	• Blue and yellow symbols should have a size greater than 30 arc minutes to ensure detectability of the colours.	All functions	All OPRs related to display of text and symbols, including: 2.7.4 Clearances and Instructions 2.12.1 Common Controller Workstation 2.15.2 Strip Format Creation 3.4.1 Displayed Data
	• Red and green symbols should have a size greater than 15 arc minutes to ensure detectability of the colours.	All functions	All OPRs related to display of text and symbols, including: 2.7.4 Clearances and Instructions 2.12.1 Common Controller Workstation 2.15.2 Strip Format Creation 3.4.1 Displayed Data
	• The height to width ratio for alphanumeric characters should be between 1:0.7 and 1:0.9.	All functions	All OPRs related to display of alphanumeric characters, including: 2.6.2 General Flight Planning 2.7.4 Clearances and Instructions 2.12.1 Common Controller Workstation 2.7.4 Clearances and Instructions 2.15.2 Strip Format Creation 3.4.1 Displayed Data
	• Where large amounts of text are presented, symbol sizes should not exceed 24 arc minutes so that reading efficiency is not impaired.	All functions	2.4.8 Help 2.12.1 Common Controller Workstation 3.2.1 Control Tower Workstation

Design Consideration	Guidelines	Related ATC Functions	Related OPRs
Screen Consistency	• The use of colour on different screens or windows within the same application environment should be consistent.	All functions	All OPRs related to displays.
	• Correlation of colour use between situation displays and strip displays may not be necessary, but should be examined by testing operational scenarios.	Receipt Analysis	2.12.1 Common Controller Workstation 3.4.1 Display Data
Additional Coding Methods	• In general, colour should not be used as an isolated coding method. Redundant coding, such as alphanumerics, is recommended. This is especially important as the number of coding categories increases.	All functions	All OPRs where colour may be used as a highlighting technique, including: 2.2.2 Adapted/Dynamic Data 2.4.6 Transfer of Jurisdiction 2.4.7 Pointout 2.4.22 Graphic Delineation Capabilities 2.6.3 Flight Plan Processing 2.7.1 Position Reports 2.13.1 Automatic Flight Strip Output 2.15.2 Strip Format Creation 3.4.1 Displayed Data 4.2 Altitude Reservation Evaluation
	• Because of the criticality of the alert function, redundant coding methods such as alphanumerics, wink or a supplementary auditory signal should be employed.	Receipt Analysis	All OPRs related to alerts, including: 2.3.2 System Performance Modelling 2.5.1 Aircraft States 2.7.4 Clearances and Instructions 2.7.5 Conflict Detection 2.7.6 Conflict Prediction 2.7.9 Altitudes 2.8.3 Airspace Related Requirements 2.8.4 Flight Environment Changes 3.4.1 Data Display
Display Stability and Reliability	• All displays on which colour has been implemented to reflect meanings in relation to the data should be periodically tested to ensure stability of the colour display.	All Functions	All OPRs related to displays.
User Control of Displays	• Restrict the control that workstation users have over colour coding to minor variations in brightness and contrast (such as those usually provided on the front of a monitor. Because of the small number of colours that will likely be used, too much control will cause colours to be compromised.	All Functions	All OPRs related to displays.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The trend in ATC displays is to apply colour. The primary motivations for this seem to be the availability of the technology, indications that colour can be helpful in certain situations, and that controllers prefer colour displays. Considering that controllers know the criticality and operational aspects of their jobs, their perception that colour is beneficial carries significant weight. The challenge for display designers is to ensure that colour is introduced so that the performance of tasks by controllers is not impaired and hopefully enhanced. The guidelines provided in this report represent a conservative approach to the application of colour.

The conclusions that can be drawn as a result of this report are reflected in the background discussion and guidelines presented in Section 5. In general, the use of colour has been shown by a number of researchers to be useful for certain functions on video screens. These functions include grouping related items, searching for and recognizing items and in attracting the attention of the user.

There are, however, physiological, perceptual and hardware limitations that must be carefully considered when applying colour to displays. These include the colour vision characteristics of the Canadian ATC population, the restricted number of colours that can be used effectively and the colour reliability and expected life of video displays. Although it is being considered by most ATC system designers internationally, relatively few controlled studies have been performed examining the effects of using colour in the ATC environment.

The issues raised in this report give rise to a number of recommendations for further investigation in areas that could guide beneficial colour use. These recommendations are described below in order of their perceived importance.

a. The effects of colour use on controller task performance should be investigated through controlled studies to measure the effects of colour use on ATC tasks in a simulated ATC environment. The available literature does not adequately consider the complexity and interaction of display elements that will be part of an ATC display system which satisfies CAATS operational performance requirements.

b. This report suggests that large screen displays should concentrate important information in the centre of the display. The use of peripheral screen areas, even for secondary information, is questionable because of poor visibility and risk of information overload. Further investigation is necessary to examine these issues and their impact on controller performance.

c. Controllers are required to interact with their displays over long periods of time. Studies have suggested that prolonged viewing may cause visual fatigue, though colour has not been conclusively identified as a factor. Further investigation is required to examine the effects of prolonged viewing, particularly with regard to high information density on large screen displays.

d. The guidelines presented in this report recommend the use of redundant coding for items coded with colour. This reinforces colour coding, reduces potential problems for controllers with colour vision deficiencies and enhances the consistency of the display design for both monochrome and colour stations. Further investigation of redundant coding methods for application in the ATC environment is necessary.

e. The stability and life expectancies of the large screen colour CRTs and their potential effects on the controllers should be examined. A number of the contacts consulted for this report expressed concern about large screen displays. There are two main types of concerns: the reliability of the colour production technology and the potentially harmful effects of the displays on the user over prolonged use. Acceptable tolerances for hardware characteristics such as blooming and misregistration should be determined so as not to interfere with the performance of controller tasks. Further work should be done to assess the safety of large CRT displays.

f. The colour vision characteristics of the Canadian controller population should be investigated with regard to their implications for the use of colour. The tests currently used to assess the colour vision of Canadian controllers may not detect all those with colour vision deficiencies. The operational impact of colour use cannot, therefore, be fully described. The presence of controllers with colour deficiencies may affect the use of redundant coding and choice of useable colours. Screening methods used for selecting candidates for ATC training may also have to be reevaluated. To aid in the design of systems using colour, the colour vision characteristics of the controller population should be measured in more detail.

REFERENCES

Alpern, M. (1972). Eye movements. In D. Jameson and L. Hurvich (Eds.), Handbook of Sensory Physiology (Vol. VII/4, Visual Psychophysics). New York: Springer Verlag.

Apiki, S., Eglowstein, H., & Grehan, R. (1989, November). The brains behind the graphics. BYTE. pp. 178-198.

Arden, G. B., & Jacobson, J. J. (1978). A simple grating test for contrast sensitivity: Preliminary results indicate value in screening for glaucoma. Invest. Opthalmol, 17, 23-32.

Arnulf, A., Dupuy, O., & Flamant F. (1951). Les microfluctuations d'accommodation de l'oeil et leur influence sur l'image retinienne. C. R. Hebd. SÅanc. Acad. Sci., 232, 438-440.

Bahill, A. T., & Stark, L. (1975). Overlapping saccades and glissades are produced by fatigue in the saccadic eye movements system. Experimental Neurology, 48, 95-106.

Bahill, A. T. & Troost, B. T. (1979). Types of saccadic eye movements. Neurology, 29, 1150-1152.

Barlow, H. B. (1972). Dark and light adaptation: Psychophysics. In D. Jameson and L. Hurvich (Eds.), Handbook of Sensory Physiology (Vol. VII/4, Visual Psychophysics). New York: Springer Verlag.

Bartleson, C. J. (1980). Colorimetry. In F. Grum (Ed.), Optical Radiation Measurements (Vol. 2, Color Measurements). New York: Academic Press.

Bartleson, C. J., & Brennenman, E. J. (1967). Brightness perception in complex Fields. J. Opt. Soc. Am., 57, 953-957.

Bartleson, C. J., & Grum, F. (Eds.). (1984). Optical Radiation Measurements, (Vol. 5, Visual Measurements). New York: Academic Press.

Bartley, S. H., & Ball, R. J. (1968). Effects of intermittant illumination on visual acuity. Am. J. Optom. Arch. Am. Acad. of Optom., 45, 458-464.

Berens, C., & Sells, S.B. (1944). Experimental studies on fatigue of accommodation I. Arch. Ophth., 31, 148-159.

Berens, C., & Sells, S. B. (1950). Experimental studies on fatigue of accommodation II. Amer. J. Ophth., 33, 47-58.

Boff, K. R., Kaufman, L., & Thomas, J. P. (Eds.). (1986a). Handbook of Perception and Human Performance (Volume 1: Sensory Processes and Perception). New York: Wiley Interscience.

Boff, K. R., Kaufman, L., & Thomas, J. P. (Eds.). (1986b). Handbook of Perception and Human Performance (Volume 2: Cognitive Processes and Performance). New York: Wiley Interscience.

Borish, I. (1975). Clinical Refraction (3rd. ed.). Chicago: Professional Press.

Bourdy C., Vienot, F., Monot A., & Chiron A. (1985). Spatial contrast detection for colour patterns under selective chromatic adaptation. Display Technology and Applications, 6(1), 43-51.

Boyce, P. R. (1981). Human Factors in Lighting. London: Applied Science Publishers.

Boynton, R. M. (1979). Human Colour Vision. New York: Holt, Rinehart and Winston.

Breinin, G. M., & Chin, N. B. (1973). Accommodation, convergence and aging. Documenta Ophthalmalogica, 34, 109-121.

Brozek, J., Simonson, E., & Keys, A. (1950). Changes in performance and in ocular functions resulting from strenuous visual inspection. Am. J. Psychology, 63, 51-66.

Bryngdahl, O. (1966). Perceived contrast variation with eccentricity of spatial sine wave stimuli: Size determination of receptive field centres. Vision Res., 5, 553-565.

Bundesen, C., & Pedersen, L. F. (1983). Color segregation and visual search. Perception and Psychophysics, 33, 487-493.

Burnham, R. W., Hanes, R. M., & Bartleson, C. J. (1963). Color: A Guide to Basic Facts and Concepts. New York: John Wiley and Sons.

Cahill, M. C., & Carter, R. C. (1976). Color code size for searching displays of different density. Human Factors, 18(3), 273-280.

Campbell, F. W. (1974). The transmission of spatial information through the visual system. In F. O. Schmitt and F. D. Worden (Eds.), The Neurosciences: Third Study Program (pp. 95-103). Cambridge, Mass: MIT Press.

Campbell, F. W., & Westheimer, G. (1959). Factors influencing accommodation responses of the human eye. J. Physiol., 151, 285.

Campbell, F. W., & Green, D. G. (1965). Optical and retinal factors affecting visual resolution. J. Physiol., 181, 576-595.

Campbell, F. W., Robson, J. G., & Westheimer, G. (1959). Fluctuations of accommodation under steady viewing conditions. J. Physiol., 145, 579-594.

Canadian Automated Air Traffic System Project (CAATS) (1989). Operational Performance Requirements (Version 1.0, Transport Canada TP9166E). Ottawa: Transport Canada.

Charman, W. N., & Whitefoot, H. (1978). Astigmatism, accommodation and visual instrumentation. Appl. Opt., 17, 3903-3910.

Charman, W. N., & Tucker, J. (1978). Accommodation and colour. J. Optical Society of America, 68, 459-471.

Charman, W. N., & Tucker, J. (1978). Accommodation as a function of object form. Am. J. Optometry and Physiol. Optics, 55, 84-92.

Charman, W. N., & Tucker, J. (1977). Dependence of accommodation response on the spatial frequency spectrum of the observed object. Vision Res., 17, 129-139.

Christ, R. E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17(6), 542-570.

Collins, J. B., & Pruen, B. (1962). Perception time and visual fatigue. Ergonomics, 5, 533-538.

Cowan, W. (1987). Colorimetric Properties of Video Monitors (Notes for a short course presented at the Annual Meeting of the Optical Society of America). Ottawa: Division of Physics, National Research Council of Canada.

Craig, A. (1987). Diurnal variation, task characteristics, and vigilance performance. Human Factors, 29, 675-684.

Craig, A., & Condon, R. (1984). Operational efficiency and time of day. Human Factors, 26, 197-205.

Crawford, B. H. (1947). Visual Adaptation to brief conditioning stimuli. Proc. Roy. Soc., 134B, 283-302.

Cunitz, R. J., & Steinman, R. M. (1969). Comparison of saccadic eye movements during fixation and reading. Vision Res, 9, 683-693.

David, H. (1984a). Background to the Use of Colour in ATC Displays (EEC Report No. 170, Volume 1). Bretigny-sur-Orge, France: Eurocontrol Experimental Centre.

David, H. (1984b). Background to the Use of Colour in ATC Displays (ECC Report No. 170, Volume 2). Bretigny-sur-Orge, France: Eurocontrol Experimental Centre.

David, H. (1984c). Use of Colour on Electronic Data Displays (Preliminary Study), (EEC Report No. 171). Bretigny-sur-Orge, France: Eurocontrol Experimental Centre.

Davson, H. (Ed.). (1962). The Eye (Vol. 3, Muscular Mechanisms). New York: Academic Press.

de Weert, M. M. (1987). Advisory Report on the Introduction of Colour in ATC (EEC Task ATO2, EEC Report No. 200). Bretigny-sur-Orge, France: Eurocontrol Experimental Centre.

Diehl, S., & Eglowstein, H. (1990, March). A VGA on every desk. BYTE. 126-138.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behaviour. Psychol. Rev., 66, 181-201.

Ferguson, H. M., & Stevens, W. R. (1956). Relative brightness of coloured light sources. Electrical Review, 18, 849-850.

Ferguson, H. M., Reeves, J. & Stevens, W. R. (1953). Discomfort glare comparison of mercury, sodium and tungsten light sources. Electrical Review, 14, 355-358.

Fincham, E. F. (1951). The accommodation reflex and its stimulus. British J. Ophthal., 35, 381-393.

Fincham, E. F., & Walton, I. (1957). The reciprocal actions of accommodation and convergence. J. Physiol., 137, 488-508.

Finlay, D., & Wilkinson, J. (1984). The effects of glare on the contrast sensitivity function Human Factors, 26, 283-287.

Ford, A., White, C. T., & Lichtenstein, M. (1959). Analysis of eye movements during free search. J. Opt. Soc. Am., 49, 287-292.

Galitz, W. (1989). Handbook of Screen Format Design. Wellesley, MA: QED Information Sciences, Inc.

Gibson, C. P. (Ed.). (1984). Colour Coded vs. Monochrome Electronic Displays. NATO Conference at the Royal Aircraft Establishment, Farnborough, England.

Gogel, W. C.. & Strum, R. D. (1972). A comparison of accommodative and fusional convergence as cues to distance. Perception and Psychophysics, 11, 166-168.

Grandjean, E. (1988). Fitting the Task to the Man: A Textbook of Occupational Ergonomics (4th Edition). London: Taylor & Francis.

Grover, D. (Ed.) Visual Display Units and their Application. London: IPC Science and Technology Press.

Harpster, J. L. (1989). Visual performance on CRT screens and hard-copy displays. Human Factors, 31(3), 247-257.

Hopkin, V. D. (1989). Private communication.

Hopkin, V. D. (1980). The measurement of the air traffic controller. Human Factors, 22(5), 547-560.

Illumination Engineering Society. (1987). IES Lighting Handbook. New York: I. E. S.

Juris, M., & Velden, L. (1977). The pupillary response to mental overload. Physiological Psychology, 5, 421-424.

Kahneman, D. (1973). Attention and Effort. Englewood Cliffs, NJ: Prentice-Hall.

Kelly, D. H. (1977). Visual contrast sensitivity. Opt. Acta, 24, 107-129.

King, V. (1972). Discomfort glare from flashing sources. J. Am. Optom., 43, 53-56.

Kinney, G. C., & Culhane, L. G. (1978). Color in Air Traffic Control Displays: Review of the Literature and Design Considerations (MTR-7728). Washington: MITRE Corp.

Kurtz, J. I. (1938). An experimental study of ocular fatigue. Am. J. Optom., 15, 86-117.

Leibowitz, H. W., Post, R., & Ginsburg, A. (1980). The role of fine detail in visually controlled behaviour. Invest. Ophthalmol. Vis. Sci., 19, 846-848.

Leibowitz, H. W. (1977). Visual perception and stress. In G. Borg (Ed.), Physical Work and Effort (Wenner-Gren Center International Symposium Series, No. 28) (pp. 25-37). New York: Pergamon Press.

Leibowitz, H. W., & Owens, D. A. (1978). New evidence for the intermediate position of relaxed accommodation. Documenta Ophthalmologica, 46, 133.

Lovasik, J. V., Matthews, M. L., Kergoat, H. (1989). Neural, optical, and search performance in prolonged viewing of chromatic displays. Human Factors, 31(3), 273-289.

Lowenstein, O., & Lowenfeld, I. E. (1951). Types of central autonomic innervation and fatigue. A.M.A. Arch. Neurol. and Psychiatry, 66, 580-599.

Luckiesh, M., & Moss, F. K. (1935). Fatigue of the extrinsic ocular muscles while reading under sodium and tungsten light. J. Opt. Soc. Amer., 25, 216-217.

Luria, S. M. (1986). The effects of set size on colour matching using CRT displays. Proceedings of the Human Factors Society, 30th Annual Meeting (pp. 49-61). Santa Monica: HFS.

Lynn, R. (1966). Attention, Arousal, and the Orientation Reaction. New York: Pergamon Press.

Matthews, M. L., Lovasik, J. V., & Mertins, K. (1989). Visual performance and subjective discomfort in prolonged viewing of chromatic displays. Human Factors, 31(3), 259-271.

Murrell, D. (1965). Ergonomics: Man in His Working Environment. London: Chapman and Hall.

Norman D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Norman, D. A., & Draper, S. W. (Eds.). (1986). User Centered System Design. Hillsdale, NJ: Lawrence Erlbaum and Associates.

Paul, L. E. (1986). Colour Versus Monochrome for Air Traffic Control Displays. Atlantic City, NJ: FAA Tech. Centre.

Paul, L. E. (1986). Some Human Factors Considerations in Air Traffic Control Display Requirements (DOT/FAA/CT-TN86/28) Washington, DC: U.S. Department of Transportation.

Rayner, K. (1978). Eye movements in reading and information processing. Psych. Bull., 85(3), 618-660.

Society of Automotive Engineers. (1988). SAE Aerospace Recommended Practice: Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays (SAE-ARP4032). Washington, DC: SAE.

Salvendy, G. (Ed.). (1987). Handbook of Human Factors. New York: Wiley Interscience.

Schneider, G. G. (1969). Two visual systems. Science, 163, 895-902.

Sekuler, R. (1974). Spatial vision. Ann. Rev. Psychol., 25, 195-232.

Semmlow, J. L., & Hung, G. (1979). Accomodative and fusional components of fixation disparity. Invest. Ophthal. and Vis. Sci., 18, 1082-1086.

Simonson, E., & Brozek, J. (1948). Effects of spectral quality of light on visual performance and fatigue. J. Opt. Soc. Am., 38, 830-840.

Simonson, E., & Brozek, J. (1948). Effects of illumination on visual performance and fatigue. J. Opt. Soc. Am., 38, 384-397.

Smarte, G., & Baran, N. M. (1988, September). Face to face: Where are we now, and where are we going? BYTE. pp. 243-252.

Smith, S. L., & Mosire, J. N. (1986). Guidelines for Designing User Interface Software (ESD-TR-86-278, MTR 10090). Bedford, Mass: MITRE Corp.

Snyder, H. L. (1988). Image quality. In M. Helander (Ed.), Handbook of Human-Computer Interaction (pp. 437-444). New York: Elsevier Science Pub.

Stewart, G, A. (1988, February). Multiscan color monitors. BYTE. pp. 100-115.

Stewart, T. F. M., Ostberg, O., & Mackay, C. J. (1974). Computer Terminal Ergonomics - A Review of Recent Human Factors Literature (2nd Edition).

Sutcliffe, A. (1989). Task analysis, systems analysis and design: Symbiosis or synthesis?. Interacting with Computers: the Interdisciplinary Journal or Human-Computer Interaction, 1, 6-12.

Tansley, B. W. & Boynton, R. M. (1978). Chromatic border perception: The role of red- and green-sensitive cones. Vision Res., 18, 683-697.

Tansley, B. W., & Lakowski, R. (1973). Simulated lens, macular pigment and illumination changes and their effects upon colour vision. Paper presented at the Second International Congress on Colour (AIC), York, England.

Tansley, B. W., & Glushko, R. (1978). Spectral sensitivity of long-wavelength-sensitive photoreceptors in dichromats determined by elimination of border precepts. Vision Res., 18, 699-706.

Teicher, W. H., Christ, R. E., Corso, G. M. (1977). Color Research for Visual Displays (Report No. ONR CR213-102-4F. Washington, DC: U.S. Office of Naval Research Technical.

Theios, J. (1975). The components of response latency in simple human information processing tasks. In P. M. A. Rabbitt and S. Dornic (Eds.), Attention and Performance V (pp. 418-440). New York: Academic Press.

Tijerina, L. (1984). Video Display Terminal Workstation Ergonomics. Dublin, OH: OCLC Online Computer Library Center, Inc.

Treisman, A. M. (1982). Perceptual grouping and attention in visual search for features and objects. Journal of Experimental Psychology: Human Perception and Performance, 8, 194-214.

Turpin, B., & Buck, L. (1987). Displaying supplementary information for air traffic control. Proceedings of the Annual Conference of the Human Factors Association of Canada (pp. 219-222). Toronto, ON: Human Factors Association.

Valberg, A., & Tansley, B. W. (1977). Tritanopic purity difference function to describe the properties of minimally distinct borders. J. Opt. Soc. Am., 67, 1330-1336.

Van der Veer, G. C., & Mulder, G. (Eds.). (1988). Human-Computer Interaction: Psychonomic Aspects. Berlin: Springer-Verlag.

Van Cott, H. P., & Kincade, R. G. (Eds.). (1972). Human Engineering Guide to Equipment Design. New York: Wiley Interscience.

Vos, J. J. (1984). Disability glare: A state of the art report. C.I.E. Journal, 3(2), 39-53.

Vroemen, M. W. (1986). Colour in CRT-Display Design: Lay-out and Coding. Utrecht, Holland: University Paper, University of Utrecht, Department of Experimental Psychology.

Weitzman, D. O. (1986). The Use of Color in Complex Information Displays. McLean, VA: MITRE Corp.

Williams, L. J. (1982). Cognitive load and the functional field of view. Human Factors, 24, 683-692.

Wilson, D. L., & Crawford, R. (1989). Color contrast requirements for legibility of colour symbology displayed against color backgrounds. Proceedings of the Human Factors Society 33rd Annual Meeting (pp. 1373-1377). Santa Monica: HFS.

Worthey, J. A. (1979). Under-stimulation of scotopic system by fluorescent light. J. Opt. Soc. Am., 69 (10), 1487.

Wyszecki, G., & Stiles, W. S. (1984). Color Science (2nd. ed). New York: John Wiley and Sons.

APPENDIX A
EXPERTS AND RESEARCHERS

Hugh David, Ph.D.
Eurocontrol Research Centre
B.P. 15
91222 Bretigny-sur-Orge
France
Telephone: 33-1-69-88-7673

Jim Guttman, Ph.D.
Federal Systems Division
IBM Corp.
Rockville, MD
20850
Telephone: (310) 640-3664

Mr. Chris Metcalfe
Head of RD1
Civil Aviation Authority
CAA House
45 to 59 Kingsway
London WC2B6TE
Telephone: 44-71-832-5218

Frank Yohe
AAP 200
Federal Aviation Administration
800 Independence Ave. SW
Washington, DC
20591
Telephone: (202) 267-9497

Capt. Guy St. Saveur
ESD/XR
Hanscom AFB, MA
01731-5000
Telephone: (617) 271-4717

Barbara J. Ford
Defence Research Establishment
Ottawa, Ontario
Telephone: (613) 998-2091

Dr. Ed Buckley, ACD-310
Lee Paul, ACD-340
Federal Aviation Administration
Technical Centre
Atlantic City International Airport
New Jersey, 08405
Telephone: (609) 484-4864

Hughes Aircraft of Canada Ltd.
8100 Granville Ave.
Suite 900
Richmond, BC V6Y 3T6
Telephone: (604) 273-5239

Russ Benel, Ph.D.
MITRE Corp.
Civil Systems Division
7525 Colshire Dr.
McLean, VA 22102-3481
Telephone: (703) 883-6152

Maria Picardi
Mail Stop PC 218
MIT Lincoln Laboratories
244 Wood St.
Lexington, MA
Telephone: (617) 981-4391

APPENDIX B
CHROMATICITY DIAGRAM

The chromaticity coordinates are represented by the CIE 1976 chromaticity diagram with associated colour areas is shown in Figure B-1. Here, u' and v' coordinates are defined as follows:

$$u' = 4X / (X + 15Y + 3Z)$$

$$v' = 9Y / (X + 15Y + 3Z)$$

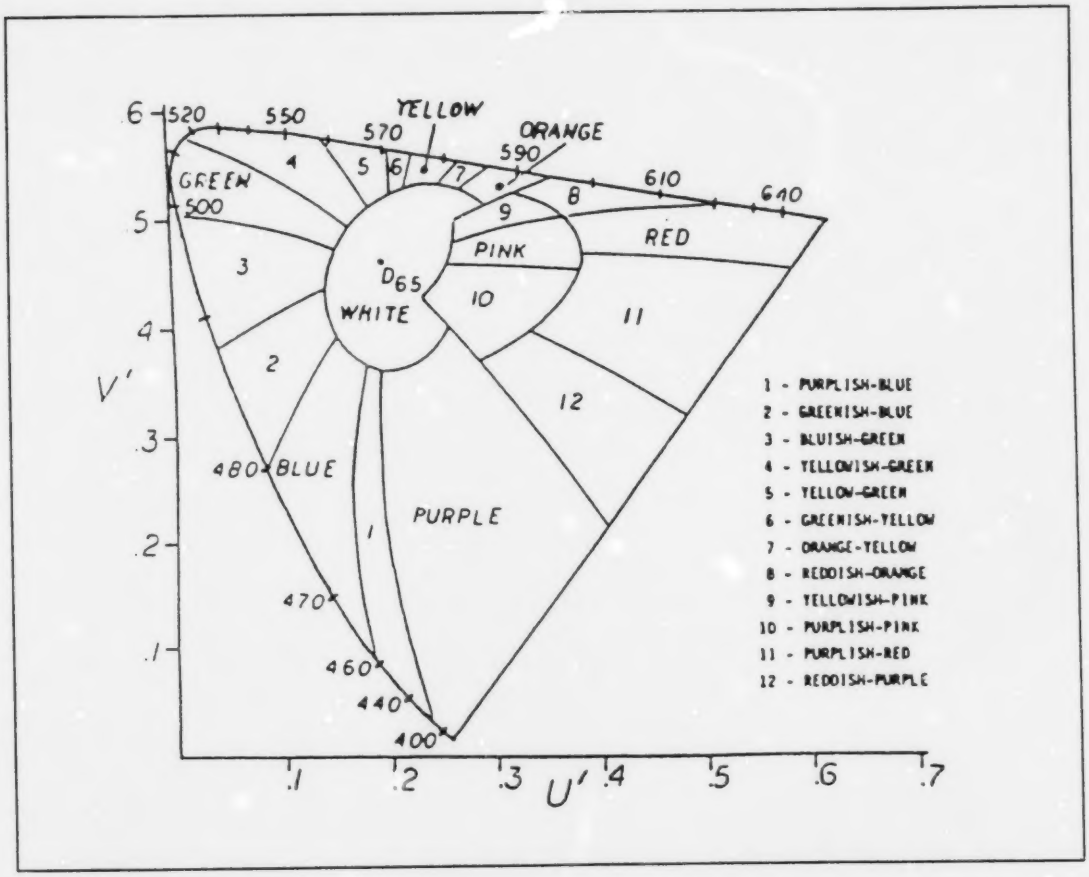

FIGURE 3: CIE 1976 Chromaticity (SAE, 1989)

The distances in the CIE system are not proportional to differences in our perception of colour. Since perceptual distances in the colour space are important in the presentation of colour information on displays, work has been done in relating colour contrast perception to various colour space transformations. (Snyder, 1988, p 456) The purpose of this effort is to predict perceived colour difference, which can be used to examine the effect of having several colours on one display screen.

The CIE recommendations include two colour difference equations known as the CIELAB and CIELUV equations. Since there appears to be little difference in how each of the equations agrees

with actual visual data, we will consider only CIELUV here. (SAE, 1989, p C-14) The CIELUV equation is expressed as follows:

$$E(L^*u^*v^*) = [(L_1^* - L_2^*)^2 + (u_1^* - u_2^*)^2 + (v_1^* - v_2^*)^2]^{0.5}$$

where,

$E(L^*u^*v^*)$ = distance between the two colours,
L_1^*, L_2^* = the L* values of the two colours,

u_1^*, u_2^* = the u* values of the two colours, and

v_1^*, v_2^* = the v* values of the two colours.

$$L^* = 116\ (Y/Y_n)1/3 - 16$$

$$u^* = 13\ L^*\ (u' - u'_n)$$

$$v^* = 13\ L^*\ (v' - v'_n)$$

and

Y_n maximum luminance within the image under consideration (for self luminant displays)

u'_n and v'_n values of reference white under consideration

It has been recommended that any two colours in a set that must be discriminated should differ in $E(L^*u^*v^*)$ by at least 40 units. According to the capabilities of most available colour CRTs, this implies that at least 7 to 10 simultaneous colours could be discriminated by a typical user. (Snyder, 1988, p 456).

In the case where it is desired to enhance legibility by displaying one colour against a background of another colour, the delta $E_{Yu'v'}$ legibility measure can be used:

$$E(Yu'v') = [(155Y/Y_M)^2 + (367u')^2 + 167v')^2]^{0.5}$$

where,

Y_M = the luminance of the brighter of a character/background pair.

The constants in the Delta $E_{Yu'v'}$ equation were derived empirically so that a maximum reading response speed is reached at 100 E units.

APPENDIX C
TASK DECOMPOSITION

Today, our challenge is to build interactive real-time control and decision support systems which can augment users problem-solving and decision-making capabilities. The kind of support we build into these systems has become even more crucial. Without the appropriate functionality, even the most advanced user interface will fail. Emphasis is on the user (air traffic controller) and his/her interaction with the system as the starting point in system design.

This work has been done for air traffic controllers on several occasions. The team involved in the production of this report has over one hundred years of ATC experience and twenty five years of experience in the design of an advanced ATC work station. They have spent many hours with highly experience human factors engineers and scientists in the development of controller tasks and resultant man machine systems necessary to perform the ATC functions. This work was analyzed by a group of ATC experts to determine applicable to CAATS.

In contemporary man-machine systems, the man-machine interface includes a work station containing various control and display devices that people use in the performance of their job. Also important are the software which constrain or facilitate the human-computer interaction, the task allocation and operating procedures that structure a person's interaction with the computer, and other conditions of the work environment that influence job performance.

In developing these man-machine systems a multi-step approach was used. Each step produces a set of well-defined outputs which are the basis for the next steps. Additionally, each of the steps included the sequence of specification, validation, and evaluation.

In the analyze tasks and human performance step, the Operational Concept is produced. Man-machine functions are further decomposed down to tasks and atomic task elements and allocated between crew-members. Interface design between crew-members are done and each job position is analyzed with respect to failures modes and constraints (workload). Functionality is added to deal with these exceptions. The human performance and skill level are derived based on the analysis and man-machine dialogues are defined, in conceptual terms, A man-machine dialogue is defined as a sequence of user information processing tasks; each tasks characterized by its interaction and logical display.

We are here concerned with the tasks derived for a given automation, their information requirements, the detailed support needed for these tasks and the workload and performance requirements imposed on the users. Thus, the objective of the task analysis is to analyze the decision aids that the man machine system must provide to match human decision making strategies and human information processing. How the detailed interactions between the human and the machine is accomplished is not the concern in this step and is elaborated in the next step. After the task elements are derived and allocated to the individual crew-member, a cognitive task analysis is performed to establish, the requirements of specific machine support, the user skill and performance requirements. As a bridge to the man-machine interface dialogue, logical display are defined.

After this step is performed, the user task elements and support functions have been derived and the workload and performance requirements of the user positions analyzed. The perceptual and manual aspects of the man machine interface becomes more important when the detailed design and

analysis of the interface is done (interaction techniques, coding techniques). Thus we separate these two levels of task analysis, the first level analyzing what the interface shall communicate between the human and machine and the next level how to implement a given interface goal.

After the tasks have been derived, they are allocated to user positions, in such a way that a coherent job is formed. By the allocation, new interface functions and coordination functions (when the same tasks are allocated to more than one position for workload considerations) are established.

ATC specialists with extensive human factors training, obtained during the design of the FAA's Advanced Automation System, identified the ATC workstation activities performed by operational ATC specialists. This work was done to develop a requirements matrix of functional tasks performed by a controller in the performance of his duties. Using the matrix, the type of tasks, the information received (the kind of data presented), the information source (the type of display or view presented), the frequency of use and the criticality were also identified. The task type, information received, and information source may be used to describe the human machine interface required between the controller and the workstation.

Table C-1 associates these controller activities with system communication messages or direct observation. Communication messages can be to or from another controller or supervisor within the facility, a computer generated display or from someone outside the facility such as another controller or pilot.

The components of the table are summarized below:

Task Type: Tasks are categorized as being one or more of four types:

- E (entry) - Entry of data into CAATS by a function key or by message through a keyboard.
- R (receipt) - Receipt of information by means other than by voice communications; includes system messages/displays and direct observation.
- A (analysis) - Cognitive assessment and evaluation of data, involving no input or output of information unless combined with another task type.
- VC (verbal communication) - Transfer or exchange of information with another person via telecommunications, radio or directly.

Information Received (by the controller):
Information can be received by computer generated data or direct observation. Voice data is not addressed.

Information Source:

The source of information received can be a controller workstation display or direct observation.

Frequency/Criticality:

Tasks are assessed relative to all other controller tasks as having HIGH (H), MEDIUM (M) or LOW (L) frequency of performance and as having EXTREME (E), HIGH (H), MEDIUM (M) or LOW (L) criticality.

Tentative logical displays related to ATC were named for use in implementing a human machine interface. Each task is assigned to a display where appropriate.

TABLE 2: ATC Task Requirements Matrix

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
1.0 - ACTIVITY - Perform Situation Monitoring				
1.1 - TASK - Checking And Evaluating Separation				
1.1.1 - Subtask - Review Flight Data Display For Present And/Or Future Aircraft Separation	R/A	Flight Data Entry, Flight Data Readout Area	Flight Data Display	H/E
1.1.2 - Subtask - Review Situation Display For Potential Violation Of Aircraft Separation Standards	R/A	Full Data Block, Partial Data Block,Target Position Symbol, Obstruction, Route Display	Situation Display	H/E
1.1.3 - Subtask - Request Continuous Range Readout	E/R/A	Continuous Range Readout	Situation Display	L/L
1.1.4 - Subtask - Project Mentally An Aircraft's Future Position/Altitude/Path	R/A	Full Data Block, Limited Data Block, Target Position Symbol, Obstruction, Graphic ATC Weather, Flight Data Entry	Situation Display, Flight Data Display	H/H
1.1.5 - Subtask - Request Range/ Bearing/Time Message, With Options	E/R/A	Fix/Time Readout, Range/Bearing Readout, Range/Bearing/Fix Readout	Situation Display	L/L
1.1.6 - Subtask - Force/Quick Look Full Data Block(s) To Examine Track Information On Aircraft	E/R/A	Full Data Block	Situation Display	L/M
1.1.7 - Subtask - Determine Whether Aircraft May Be Separated By Less Than Prescribed Minima	A	N/A	N/A	H/E
1.1.8 - Subtask - Select Flight Data Entry Sorting Priority Scheme	E	N/A	N/A	L/L
1.1.9 - Subtask - Observe Track Velocity/Distance Vector To Project Aircraft Movement	E/R/A	Track Distance Vector, Track Velocity Vector	Situation Display	H/M
1.1.10 - Subtask - Suppress Continuous Range Readout	E	N/A	N/A	L/L
1.1.11 - Subtask - Review Situation Display For Potential Violation Of Airspace Separation Standards	R/A	Full Data Block, Limited Data Block, Target Position Symbol,Route Display, Special Use Airspace	Situation Display	H/E
1.1.12 - Subtask - Review Displays For Potential Violation Of Flow Restrictions	R/A	Full Data Block, Target Position Symbol,Metering Advisory List Entry, Traffic Management Information Graphic ATC Weather, Flight Data Entry	Situation Display, Special Lists, Metering Advisory List, Flight Data Display, Tfc Mgt Info	H/E
1.1.13 - Subtask - Review Situation Display For Potential Violation Of Conformance Criteria	R/A	Target Position Symbol,Altitude Nonconformance Indicator, Lateral Nonconformance Indicator, Geographic Map Data	Situation Display, Full Data Block	H/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
1.1.14 - Subtask - Determine Whether Airspace Separation Standards May Be Violated	A	N/A	N/A	H/E
1.1.15 - Subtask - Determine Whether Conformance Criteria May Be Violated	A	N/A	N/A	H/M
1.1.16 - Subtask - Determine Whether Flow Restrictions May Be Violated	A	N/A	N/A	H/H
1.1.17 - Subtask - Request Display Of Cleared Route For A Flight	E/R	Route Display, Planned Route Of Flight For Single Aircraft	Situation Display	L/L
1.2 - TASK - Receiving System Status Information				
1.2.1 - Subtask - Detect Equipment Service Interruption/ Restoration	R	Equipment Status Computer Outage, Usage Of Operational Functions	Direct Observations	L/M
1.2.2 - Subtask - Receive Notice Of Communication Status	R/VC	Communication Status	G.I. Message/ATC Mail	L/M
1.2.3 - Subtask - Request Report On Navaid Status	VC	N/A	N/A	L/M
1.2.4 - Subtask - Observe Posted Notice Of New/ Changed Equipment/ Operational Status	R/A	Equipment Status, Communication Status, Computer Outage, Data Communication Line Outage, Voice Communication Line Outage	System Status Information, Communications Display	L/M
1.2.5 - Subtask - Receive Notice Of Status Of Adjacent/ Backup Computer Equipment	R/VC	Adjacent/Backup ACF Automation Equipment Status	G.I. Message/ATC Mail	L/L
1.2.6 - Subtask - Record System Status Data Change	E	N/A	N/A	L/M
1.3 - TASK - Analyzing Inital Requests For Clearances				
1.3.1 - Subtask - Search Display For Inactive Flight Plan On Clearance Request	R/A	Flight Data Entry	Flight Data Display	L/L
1.3.2 - Subtask - Request Flight Data Readout	E/R/A	Flight Data Readout Area	Flight Data Display	L/M
1.3.3 - Subtask - Request Flight Data Entry Format Change	E	N/A	N/A	L/M
1.4 - TASK - Processing Departure/ En Route Time Information				

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
1.4.1 - Subtask - Enter Departure/En Route Time Message	E	N/A	N/A	L/M
1.4.2 - Subtask - Initiate Track Manually	E/R	Full Data Block, Target/Track Descriptor	Situation Display	L/H
1.4.3 - Subtask - Observe Automatic Track Start	R	Full Data Block, Target/Track Descriptor	Situation Display	M/H
1.4.4 - Subtask - Receive Departure/En Route Time Notice	R/VC	Departure Time, En Route Time	G.I. Message/ATC Mail	L/M
1.5 - TASK - Processing Requests For Flight Following				
1.5.1 - Subtask - Evaluate Conditions For Providing Flight Following	R/A	Full Data Block, Flight Data Entry, Special Lists, Alert Condition, Weather Descriptor, System Status Information	Situation Display, Flight Data Display, Special Lists, Alert & Resolution Display, System Status Information	L/M
1.5.2 - Subtask - Receive Request For Flight Following	R/VC	Flight Following Request	G.I. Message/ATC Mail	L/L
1.5.3 - Subtask - Deny Flight Following Request	E/VC	N/A	N/A	L/L
1.5.4 - Subtask - Request/Assign Beacon Code To Aircraft	E/R/VC	Beacon Code	Response Display, Flight Data Entry	L/M
1.5.5 - Subtask - Inform Pilot Of Alternate Instructions Necessary For Flight Following Service	VC	N/A	N/A	L/M
1.6 - TASK - Housekeeping				
1.6.1 - Subtask - Offset A Data Block	E	N/A	N/A	L/M
1.6.2 - Subtask - Delete Flight Data Entry And Full Data Block From ATC System	E	N/A	N/A	L/L
1.6.3 - Subtask - Suppress Display Of Flight Data Entry And Full Data Block From All Displays In Own Workstation	E	N/A	N/A	L/L
1.6.4 - Subtask - Restore Display Of Flight Data Entry And Full Data Block To All Displays On Own Workstation	E	N/A	N/A	L/M
1.6.5 - Subtask - Suppress Data Block From All Displays In Own Workstation	E	N/A	N/A	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
1.6.6 - Subtask - Restore Data Block To All Displays In Own Workstation	E	N/A	N/A	L/M
1.6.7 - Subtask - Restore Data Block to All Displays In Own Workstation	E	N/A	N/A	L/M
1.6.8 - Subtask - Suppress Flight Data Entry From All Displays In Own Workstation	E	N/A	N/A	L/L
1.6.9 - Subtask - Restore Flight Data Entry To All Displays In Own Workstation	E	N/A	N/A	L/L
1.6.10 - Subtask - Enter Flight Data Entry Notations	E	N/A	N/A	H/L
1.6.11 - Subtask - Delete Flight Data Entry Notations	E	N/A	N/A	L/M
1.6.12 - Subtask - Resequence Flight Data Entry Manually	E	N/A	N/A	L/L
1.6.13 - Subtask - Delete Controller Note	E	N/A	N/A	L/L
1.6.14 - Subtask - Update/Revise Controller Note	E	N/A	N/A	L/L
1.6.15 - Subtask - Delete Flight Data Entry And Full Data Block From Local Computer System	E	N/A	N/A	L/L
1.6.16 - Subtask - Remove Obsolete Paper Records Or Recorded Data	E	N/A	N/A	M/L
2.0 - ACTIVITY - Resolve Aircraft Conflicts				
2.1 - TASK - Performing Aircraft Conflict Resolution				
2.1.1 - Subtask - Detect Aircraft Conflict Alert Indicaton	R	Conflict Alert, Conflict Alert Indicator, Alert Type, Alert Condition, Callsign	Alert and Resolution Display, Full Data Block, Flight Data Entry Notation	L/E
2.1.2 - Subtask - Determine Validity Of Potential Aircraft Conflict Notice Or Indicaton	A	N/A	N/A	L/H
2.1.3 - Subtask - Receive Controller Notice Of Potenial Aircraft Conflict In Sector	VC	N/A	N/A	L/E
2.1.4 - Subtask - Inform Controller Of Potential Aircraft Conflict In His Sector	VC	N/A	N/A	L/E

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
2.1.5 - Subtask - Forward Notice Of Aircraft Conflict To Supervisor	E/VC	N/A	N/A	L/L
2.1.6 - Subtask - Choose Conflict Resolution Option	R/A	Conflict Resolution Advisory	Alert and Resolution Display, Situation Dispaly	L/E
2.1.7 - Subtask - Review Potential Conflict Situation For Resolution	R/A	Full Data Block, Limited Data Block, Flight Data Entry, Conflict Resolution Advisory Option	Situation Display, Flight Data Display, Alert and Resolution Display	L/E
2.1.8 - Subtask - Determine Appropriate Action To Resolve Aircraft Conflict Situation	A	N/A	N/A	L/E
2.1.9 - Subtask - Perceive Potential Aircraft Conflict Situation	R/A	Full Data Block, Limited Data Block, Flight Data Entry	Situation Display, Flight Data Display	L/E
2.2 - TASK - Performing Minimum Safe Altitude Processing				
2.2.1 - Subtask - Detect MSAW Indication Or Alarm	R	Minimum Safe Altitude Warning, Alert Type, Alert Condition, Aural Alarm	Alert and Resolution Display, Full Block Data	L/E
2.2.2 - Subtask - Forward Notice Of Valid MSAW Or Flight Assist To Supervisor	E/VC	N/A	N/A	L/L
2.2.3 - Subtask - Receive Controller Notice Of Potential MSAW In Sector	VC	N/A	N/A	L/E
2.2.4 - Subtask - Inform Controller Of Potential MSAW In His Sector	VC	N/A	N/A	L/M
2.2.5 - Subtask - Perceive Potential Low Altitude Situation	R/A	Full Data Block, Limited Data Block, Flight Data Entry, Obstruction, Geographic Map Data, Minimum Vector Altitude	Situation Display, Flight Data Display	L/E
2.2.6 - Subtask - Determine Validity Of MSAW Notice Or Indication	A	N/A	N/A	L/E
2.2.7 - Subtask - Determine Appropriate Action To Resolve Low Altitude Situation	A	N/A	N/A	L/E
2.3 - TASK - Performing Airspace Conflict Processing				
2.3.1 - Subtask - Inform Controller Of Potential Airspace Conflict In His Sector	E/VC	N/A	N/A	L/E
2.3.2 - Subtask - Receive Controller Notice Of Potential Airspace Conflict In Sector	VC	N/A	N/A	L/E

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
2.3.3 - Subtask - Request Release Of Special Use Airspace	E/VC	N/A	N/A	L/M
2.3.4 - Subtask - Receive Denial Of Use Of Special Airspace	R/VC	Rejection of Airspace Release	G.I. Message/ATC Mail	L/M
2.3.5 - Subtask - Receive Approval For Use Of Special Use Airspace	R/VC	Airspace Release Acceptance	G.I. Message/ATC Mail	L/M
2.3.6 - Subtask - Perceive Potential Airspace Conflict Situation	R/A	Full Data Block, Limited Data Block, Flight Data Entry, Geographic Map Data	Situation Display, Flight Data Display	M/H
2.3.7 - Subtask - Determine Appropriate Action To Resolve Airspace Conflict Situation	A	N/A	N/A	L/H
2.3.8 - Subtask - Determine Validity Of Airspace Conflict Notice	A	N/A	N/A	L/H
2.4 - TASK - Issuing Unsafe Condition Advisories				
2.4.1 - Subtask - Observe Display For Fixed Obstructions That May Interfere With Aircraft Flight	R/A	Obstruction, Target Position Symbol, Flight Data Entry	Situation Display, Flight Data Display, Static Information Display	L/H
2.4.2 - Subtask - Evaluate Conflict Resolution Advisory Appropriateness For Pilot/Route/Altitude/ Weather	R/A	Conflict Resolution Advisory	Situation Display, Alert and Resolution Display	L/H
2.4.3 - Subtask - Formulate Advisory/ Safety Alert Content	A	N/A	N/A	L/H
2.4.4 - Subtask - Detect Aircraft Maneuver In Response To Advisory/Alert	R/A	Target Position Symbol, Data Block, Position History	Situation Display	L/H
2.4.5 - Subtask - Issue Traffic Advisory/ Safety Alert In Regard To Traffic Proximity	VC	N/A	N/A	M/H
2.4.6 - Subtask - Inform Pilot When Clear Of Traffic	VC	N/A	N/A	M/L
2.4.7 - Subtask - Issue Advisory In Regard To A Non-Controlled Object	VC	N/A	N/A	L/H
2.4.8 - Subtask - Inform Pilot When Clear Of Non-Controlled Object	VC	N/A	N/A	L/L
2.4.9 - Subtask - Issue Advisory In Regard To Restricted Airspace Proximity	VC	N/A	N/A	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
2.4.10 - Subtask - Issue Advisory In Regard To Flight Plan Deviation	VC	N/A	N/A	L/M
2.4.11 - Subtask - Evaluate MSAW Resolution Advisory In Relation To Aircraft Type/Pilot's Intentions	R/A	MSAW Resolution Advisory, Aircraft Type, MSAW Vector	Alert and Resolution Display, Situation Display, Full Data Block, Flight Data Entry	L/M
2.4.12 - Subtask - Issue Safety Alert In Regard To Minimum Altitude	VC	N/A	N/A	L/H
2.4.13 - Subtask - Observe Display For Non-Controlled Airborne Objects That May Interfere With Aircraft Flight	R/A	Target Position Symbol	Situation Display	L/H
2.4.14 - Subtask - Determine Need For Advisory/Safety Alert/Clearance	A	N/A	N/A	L/H
2.5 - TASK - Suppressing Alerts/ Resolution Advisories				
2.5.1 - Subtask - Determine Validity/ Appropriateness Of Display Of An Alert/ Resolution Advisory	R/A	Alert Condition, Computer-Generated Conflict Resolution, Data Block	Alert and Resolution Display, Situation Display	L/H
2.5.2 - Subtask - Suppress Conflict Alert For Paired Aircraft	E	N/A	N/A	L/L
2.5.3 - Subtask - Suppress Conflict Alert For Group Suppression	E	N/A	N/A	L/L
2.5.4 - Subtask - Suppress MSAW Resolution Advisory For An Aircraft	E	N/A	N/A	L/L
2.5.5 - Subtask - Suppress MSAW Function For An Aircraft	E	N/A	N/A	L/L
2.5.6 - Subtask - Suppress Conflict Resolution Advisory For Paired Aircraft	E	N/A	N/A	L/L
2.5.7 - Subtask - Restore Specific Alert/ Resolution Advisory Function To Normal	E	N/A	N/A	L/L
3.0 - ACTIVITY - Manage Air Traffic Sequences				
3.1 - TASK - Responding To Traffic Management Constraints/Flow Conflicts				
3.1.1 - Subtask - Evaluate Traffic Management Information For Effect On Traffic Flow	R/A	Traffic Management Information, Metering Advisory List Entry, Metering Advisory	Special Lists, Metering Advisory List, G.I. Message/ATC Mail, Flight Data Entry, Traffic Management Information	H/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
3.1.2 - Subtask - Choose Option To Bring Aircraft Into Conformance With Traffic Management Restrictions	R/A	Aircraft Position and Movement, Aircraft Characteristics, Traffic Management Information, Metering Advisory	Full Data Block, Target Position Symbol, Flight Data Entry, Special Lists, TFC Management Information	L/M
3.1.3 - Subtask - Discuss Discontinuance Of Traffic Management Restriction/Traffic Reroute With Supervisor	A/VC	N/A	N/A	L/L
3.1.4 - Subtask - Review Options To Bring Aircraft Into Conformance With Traffic Management Restrictions	A	N/A	N/A	L/M
3.1.5 - Subtask - Negotiate Traffic Management Action With Pilot	VC	N/A	N/A	L/L
3.1.6 - Subtask - Receive Traffic Management Restriction	R/VC	Traffic Management Restriction	G.I. Message/ATC Mail	L/M
3.1.7 - Subtask - Receive Metering Data	R/VC	Metering Data	G.I. Message/ATC Mail	M/M
3.1.8 - Subtask - Receive Supervisor Notice To Hold/Reroute Traffic Clear Of Contingency	R/VC	Hold/Reroute Traffic	G.I. Message/ATC Mail	L/H
3.1.9 - Subtask - Request Exception To Traffic Management Restriction	E/VC	N/A	N/A	L/M
3.1.10 - Subtask - Review Traffic Demands And Traffic Management Restrictions With Supervisor	ERA/VC	Traffic Flow Information	G.I. Message/ATC Mail, Situation Display, Flight Data Display, Traffic Management Information, Metering Advisory List	L/L
3.1.11 - Subtask - Receive Supervisor Briefing On What Traffic Conditions To Expect	VC/A	N/A	N/A	L/L
3.1.12 - Subtask - Receive Approval Of Request For Exception To Flow Restriction	R/VC	Exception Approval	G.I. Message/ATC Mail	L/L
3.1.13 - Subtask - Receive Denial Of Request For Exception To Flow Restriction	R/VC	Exception Denial	G.I. Message/ATC Mail	L/L
3.1.14 - Subtask - Request Metering Advisory List	E/R	Metering Advisory List	Special Lists	L/L
3.2 - TASK - Processing Deviations				
3.2.1 - Subtask - Perceive An Altitude Or Route Deviation	R/A	Apparent Route of Flight/Altitude/Ground Speed, Intended Route of Flight/ Altitude/Ground Speed, Target Position Symbol	Full Data Block, Flight Data Entry, Position Symbol	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
3.2.2 - Subtask - Observe Aircraft Resuming Normal Flight Plan	R/A	Route Display, Assigned Altitude, Ground Speed, Target Position Symbol, Position History, Geographic Map Data	Full Data Block, Target/Track Descriptor, Situation Display	L/M
3.2.3 - Subtask - Determine Maneuver To Establish/Restore Flight Plan Conformance	A	N/A	N/A	L/M
3.2.4 - Subtask - Receive Controller Notice Of Aircraft Flight Plan Deviation	R/VC	Flight Plan Deviation	G.I. Message/ATC Mail	L/M
3.2.5 - Subtask - Inform Controller/ Supervisor Of Aircraft Flight Plan Deviation	E/VC	N/A	N/A	L/M
3.2.6 - Subtask - Detect Lateral/Altitude Non-Conformance Indication	R	Lateral Non-Conformance Indicator, Altitude Non-Conformance Indicator	Full Data Block	L/H
3.2.7 - Subtask - Request Display Of Flight Data Entry For Flight Plan	E	N/A	N/A	L/M
3.2.8 - Subtask - Evaluate Flight Data To Determine Future Course Of Action	R/A	Flight Data Entry	Flight Data Display	H/M
3.2.9 - Subtask - Evaluate Lateral Non-Conformance Indication For Action Needed	R/A	Geographic Map Data, Lateral Non-Conformance Indicator	Full Data Block, Situation Display	H
3.2.10 - Subtask - Evaluate Altitude Non-Conformance Indication For Action Needed	R/A	Geographic Map Data, Altitude Non-Conformance Indicator	Full Data Block, Situation Display	L/H
3.2.11 - Subtask - Evaluate The Observed Unreasonable Mode C Indicator In The FDB To Determine The Proper Course Of Action	A	N/A	N/A	L/M
3.2.12 - Subtask - Detect Unreasonable Mode C Indication	R	Mode C Reasonableness Check Failure Indication	Full Data Block, Situation Display	L/M
3.3 - TASK - Responding To Special Use Airspace Events				
3.3.1 - Subtask - Inform Controller/ Supervisor/Pilot Of Airspace Restriction Imposed/Release	E/VC	N/A	N/A	L/M
3.3.2 - Subtask - Receive Request For Use Of Special Use Airspace From Supervisor/Controller/Pilot	R/VC	Special Use Airspace Request	G.I. Message/ATC Mail	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
3.3.3 - Subtask - Determine Restrictions To Users Necessary Within Released Airspace	A	N/A	N/A	L/L
3.3.4 - Subtask - Observe Display Of Airspace Restriction Status Change	R	Special Use Airspace Status, Activation Period	System Status Information, Situation Display	L/M
3.3.5 - Subtask - Receive Notice Of Airspace Restriction/ Release	R/VC	Special Use Airspace Restriction/Release	G.I. Message/ATC Mail	L/M
3.4 - TASK - Establishing Arrival Sequences				
3.4.1 - Subtask - Determine Descent Time Or Point	R/A	Track Position Symbol, Metering Advisory List, Traffic Management Information, Geographic Map Data	Situation Display, Special Lists, Traffic Management Information	H/M
3.4.2 - Subtask - Project Traffic Sequence To Establish/Modify Approach Flow To Airport Or Sector	A	N/A	N/A	H/H
3.4.3 - Subtask - Observe Metering Advisory List For Metering Requirements	R/A	Metering Advisory List Entry	Metering Advisory List	M/M
3.4.4 - Subtask - Request Aircraft Be Rerouted	E/VC	N/A	N/A	L/M
3.4.5 - Subtask - Project Mentally The Range/Bearing Between Aircraft	R/A	Target Position Symbol, Full Data Block	Situation Display	H/H
3.4.6 - Subtask - Project Mentally The Arrival Flow For Aircraft Landing In Or Near This Sector	A	Target Position Symbol, Data Block, Flight Data Entry, Time	Situation Display, Flight Data Display	H/H
3.5 - TASK - Managing Departure Flows				
3.5.1 - Subtask - Validate Mode C Altitude	R/A	Mode C Altitude	Full Data Block	M/H
3.5.2 - Subtask - Enter Reported Altitude	E	N/A	N/A	M/M
3.5.3 - Subtask - Receive Notice Of Missed Approach	R/VC	Full Data Block	Situation Display	L/E
3.5.4 - Subtask - Project Traffic Sequence To Establish/Modify Departure Flow	A	N/A	N/A	H/H
3.6 - TASK - Monitoring Non-Controlled Objects				
3.6.1 - Subtask - Observe Airspace Intrusion By A Non-Controlled Object	R	Target Position Symbol, Sector Boundary, Primary Target Class	Situation Display	L/M
3.6.2 - Subtask - Enter Controller Note	E	N/A	N/A	L/L

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
3.6.3 - Subtask - Flight-Follow An Observed Non-Controlled Object	E/R/A	Target Position Symbol	Situation Display	L/L
3.6.4 - Subtask - Forward Notice Of Airspace Instrusion By A Non-Controlled Object	E/VC	N/A	N/A	L/L
3.6.5 - Subtask - Receive Notice Of Airspace Intrusion By A Non-Controlled Object	R/VC	Intrusion	G.I. Message/ATC Mail	L/L
3.7 - TASK - Responding To Temporary Release Of Airspace Requests				
3.7.1 - Subtask - Receive Controller/ Supervisor Request For Temporary Use Of Airspace	R/VC	Request for Temporary Use of Airspace, Full Data Block, Sector Boundary	G.I. Message/ATC Mail, Situation Display	L/M
3.7.2 - Subtask - Forward Approval For Temporary Use Of Airspace	E/VC	N/A	N/A	L/M
3.7.3 - Subtask - Forward Denial Of Temporary Use Of Airspace	E/VC	N/A	N/A	L/M
3.7.4 - Subtask - Suppress Map Associated With Temporary Use Of Airspace	E	N/A	N/A	L/L
3.7.5 - Subtask - Discuss Release Of Airspace For Temporary Use With Supervisor/Other Controller	VC/A	N/A	N/A	L/L
3.7.6 - Subtask - Select Map Display OF Adapted Airspace Requested For Use By Another Controller	E	N/A	N/A	L/L
3.7.7 - Subtask - Evaluate Feasibility Of Releasing Airspace Temporarily	R/A	Full Data Block, Flight Data Entry	Situation Display, Flight Data Display	L/L
3.7.8 - Subtask - Receive Notification Of Return Of Released Airspace	R/VC	Release Airspace Notification	G.I. Message/ATC Mail	L/M
3.8 - TASK - Requesting Temporary Release Of Airspace				
3.8.1 - Subtask - Request Temporary Use Of Airspace	E/VC	N/A	N/A	L/M
3.8.2 - Subtask - Receive Release/Use Of Airspace	R/VC	Release/Use of Airspace	G.I. Message/ATC Mail	L/L
3.8.3 - Subtask - Receive Rejection Of Use Of Airspace	R/VC	Rejection of Use of Airspace	G.I. Message/ATC Mail	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
3.8.4 - Subtask - Forward Notice Of Return Of Released Airspace	E/VC	N/A	N/A	L/M
4.0 - ACTIVITY - Route Or Plan Flights				
4.1 - TASK - Planning Clearances				
4.1.1 - Subtask - Receive Controller Notice On Requested Clearance Of Aircraft Leaving His Sector	R/VC	Request Clearance	G.I. Message/ATC Mail	L/M
4.1.2 - Subtask - Receive Clearance Request From ATCT/FSS/Pilot/ Supervisor	R/VC	Clearance Request	G.I. Message/ATC Mail	M/M
4.1.3 - Subtask - Receive Controller Request For Clearance/Approval	R/VC	Clearance/Approval Request	G.I. Message/ATC Mail	H/M
4.1.4 - Subtask - Forward Clearance Request To Another Controller	E/VC	N/A	N/A	H/M
4.1.5 - Subtask - Request Clearance/ Approval From Another Controller	E/VC	N/A	N/A	H/M
4.1.6 - Subtask - Receive Clearance Approval/Clearance Restrictions From Another Controller	R/VC	Clearance Approval/ Request	G.I. Message/ATC Mail	H/H
4.1.7 - Subtask - Receive Clearance Disapproval/Denial From Another Controller	R/VC	Clearance Disapproval/ Restrictions	G.I. Message/ATC Mail	L/M
4.1.8 - Subtask - Receive Alternative Suggestion For Clearance/Approval Requested Of Another Controller	R/VC	Alternative Suggestion for Clearance	G.I. Message/ATC Mail	L/M
4.1.9 - Subtask - Review Potential Impediments For Impact On Proposed Clearance	R/A	Target Position Symbol, Obstruction, Special Use Airspace Boundary, WX Descriptor, Flight Data Entry, Traffic Management Information, Metering Advisory List Entry	Situation Display, Flight Data Display, Special Lists	H/M
4.1.10 - Subtask - Discuss Clearance Alternatives With Pilot	VC	N/A	N/A	L/M
4.1.11 - Subtask - Evaluate Flight Data Entry Changes For Clearance Planning Or Future Actions	R/A	Flight Data Entry	Flight Data Display	H/M
4.1.12 - Subtask - Determine Priority Of Control Actions	A	N/A	N/A	H/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.1.13 - Subtask - Perceive Need For Amended Clearance	R/A	Flight Data Entry, Position Symbol	Flight Data Display, Situation Display	H/H
4.1.14 - Subtask - Formulate Controller Plan Of Action For Clearance Generation	A	N/A	N/A	H/H
4.1.15 - Subtask - Evaluate Mental Flight Plan Projection For Appropriateness	A	N/A	N/A	H/H
4.1.16 - Subtask - Determine Appropriate Mental Plan For Aircraft Clearance	A	N/A	N/A	L/H
4.2 - TASK - Responding To Contingencies				
4.2.1 - Subtask - Declare Emergency And Invoke Contingency Plan	ERA/VC	Contingency Plan Checklist	Static Information Display	L/E
4.2.2 - Subtask - Receive Notice Of Pilot Or Aircraft Having A Problem (e.g., Overdue, Loss of Radio Contact)	R/VC	Pilot or Aircraft Problem	G.I. Message/ATC Mail	L/E
4.2.3 - Subtask - Issue Instructions To Pilot (NORDO) For Identification Turn/ Transponder Response	VC	N/A	N/A	L/H
4.2.4 - Subtask - Detect A Pilot Or Aircraft Problem (e.g., Hypoxia, Exception Beacon Code)	R/A/VC	Pilot or Aircraft Problem, Exception Beacon Code, Lateral/ Altitude Non-Conformance Indicator	Observation of Erratic Pilot Behavior, Full Data Block	L/H
4.2.5 - Subtask - Forward Contingency Information To Supervisor/Another Controller	E/VC	N/A	N/A	L/H
4.2.6 - Subtask - Inform Designated Personnel Of Aircraft Having Flight Problems	E/VC	N/A	N/A	L/H
4.2.7 - Subtask - Request Relay Of Instructions To Pilot (NORDO) For Identification Turn/ Transponder Response	E/VC	N/A	N/A	L/M
4.2.8 - Subtask - Conduct Search For Aircraft Without Radio Contact	A/E/VC	N/A	N/A	L/H
4.2.9 - Subtask - Observe Aircraft Turn/ Transponder Response Following Identification Request	R/A	Target Position Symbol, Beacon Code	Situation Display	M/H
4.2.10 - Subtask - Conduct Radio/Radar Search For Overdue Aircraft	A/E/VC	Beacon Code, Data Block, Target Position Symbol	Situation Display	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.2.11 - Subtask - Receive Supervisor Notice Of Emergency Declared And Contingency Plan Invoked	R/VC	Emergency, Contingency Plan	G.I. Message/ATC Mail	L/E
4.2.12 - Subtask - Receive Supervisor Notice To Conduct Communications Search For Overdue/ NORDO Aircraft	R/VC	Notice to Conduct Aircraft Search	G.I. Message/ATC Mail	L/H
4.2.13 - Subtask - Receive Notice That Supervisor Will Conduct Communications Search For Overdue/ NORDO Aircraft	R/VC	Supervisor Search for Aircraft	G.I. Message/ATC Mail	L/M
4.2.14 - Subtask - Receive Pilot Notice Of Emergency Declared	R/VC	Exception Beacon Code	Full Data Block	L/E
4.3 - TASK - Recognizing Special Operations				
4.3.1 - Subtask - Perceive Presence Of Special Operation	R/A	Callsign, Route of Flight, Presence of Data Block in Special Use Airspace, Special Handling Remarks in Flight Data Entry	Situation Display, Flight Data Display	L/H
4.3.2 - Subtask - Receive Reivew/ Notice Of Special Operation	R/VC	Special Operation Information	G.I. Message/ATC Mail	L/M
4.3.3 - Subtask - Forward Notice Of Special Operations To Another Controller/ Supervisor	E/VC	N/A	N/A	L/M
4.4 - TASK - Reviewing Flight Plans				
4.4.1 - Subtask - Observe New Flight Plan Posting	R	Flight Data Entry	Flight Data Display	H/M
4.4.2 - Subtask - Review Flight Plan For Completeness	R/A	Flight Data Entry	Flight Data Display	H/M
4.4.3 - Subtask - Enter Flight Plan	E	N/A	N/A	L/L
4.4.4 - Subtask - Acknowledge New Flight Plan Receipt	E	N/A	N/A	H/L
4.4.5 - Subtask - Reveiw Flight Plan For Errors/Data List Sequence	R/A	Flight Data Entry	Flight Data Display	H/M
4.4.6 - Subtask - Receive Flight Plan From Pilot	VC	N/A	N/A	L/L
4.4.7 - Subtask - Receive Flight Plan Verbally Forwarded	VC	N/A	N/A	L/L
4.4.8 - Subtask - Query Pilot About Flight Plan	VC	N/A	N/A	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.4.9 - Subtask - Query The Relayer Of A Flight Plan	E/VC	N/A	N/A	L/M
4.4.10 - Subtask - Forward Flight Plan Verbally	VC	N/A	N/A	L/M
4.4.11 - Subtask - Enter Stereo Flight Plan	E	N/A	N/A	L/L
4.4.12 - Subtask - Enter VFR Flight Plan	E	N/A	N/A	L/L
4.4.13 - Subtask - Request Flight Plan Readout	E	N/A	N/A	L/L
4.5 - TASK - Processing Flight Plan Amendments				
4.5.1 - Subtask - Receive Flight Data Revision	R	Flight Data Entry	Flight Data Display	H/H
4.5.2 - Subtask - Emphasize Flight Data Entry Posting For Reminder Action	E	N/A	N/A	H/M
4.5.3 - Subtask - Enter Flight Plan Amendment	E	N/A	N/A	H/H
4.5.4 - Subtask - Enter Pilot's Position Report In System	E	N/A	N/A	L/M
4.5.5 - Subtask - Delete Flight Data Entry Emphasis	E	N/A	N/A	H/L
4.5.6 - Subtask - Receive Flight Plan Amendment Verbally Forwarded	VC	N/A	N/A	L/M
4.5.7 - Subtask - Receive Pilot's Position Report	VC	N/A	N/A	L/H
4.5.8 - Subtask - Forward Flight Plan Amendment Verbally	VC	N/A	N/A	L/M
4.5.9 - Subtask - Inform Controller Unable Flight Plan Amendment	E/VC	N/A	N/A	L/M
4.5.10 - Subtask - Receive Controller Advice Of Unable Flight Plan Amendment	E/VC	Unable Flight Plan Amendment	G.I. Message/ATC Mail	L/M
4.5.11 - Subtask - Receive Requested Flight Plan Changes	R/VC	Requested Flight Plan Change	G.I. Message/ATC Mail	L/M
4.6 - TASK - Receiving Transfer Of Control/Radar Indentification				
4.6.1 - Subtask - Receive Handoff Request	R/VC	Handoff Status/ Indicator	Full Data Block	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.6.2 - Subtask - Deny Handoff	E/VC	N/A	N/A	L/H
4.6.3 - Subtask - Accept Verbal Handoff/Initiate Manual Track Start	E/R/VC	Target Position Symbol	Situation Display	L/H
4.6.4 - Subtask - Accept Automatic Handoff	E	N/A	N/A	H/H
4.6.5 - Subtask - Determine That Aircraft Is Entering Sector	A	Geographic Map Data, Target Position Symbol	Situation Display	H/H
4.6.6 - Subtask - Determine Response To Handoff Request	R/A	Full Data Block, Geographic Map Data, Target Symbol	Situation Display	H/H
4.6.7 - Subtask - Receive Control Of Aircraft	R/VC	Control of Aircraft	G.I. Message/ATC Mail	L/H
4.6.8 - Subtask - Request Transfer Of Control	E/VC	N/A	N/A	L/H
4.7 - TASK - Initiating Transfer Of Control/Radar Identification				
4.7.1 - Subtask - Initiate Handoff Function	E	N/A	N/A	L/H
4.7.2 - Subtask - Observe Automatic Initiation Of Handoff	R/A	Handoff Status/ Indicator	Full Data Block	H/H
4.7.3 - Subtask - Retract Handoff	E/VC	N/A	N/A	H/H
4.7.4 - Subtask - Receive Handoff Acceptance	R/VC	Handoff Status/ Indicator, Accepted	Full Data Block	H/H
4.7.5 - Subtask - Discuss Transfer Of Control With Other Controller	VC	N/A	N/A	L/H
4.7.6 - Subtask - Initiate Verbal Handoff	VC	N/A	N/A	L/H
4.7.7 - Subtask - Receive Request For Transfer Of Control	R/VC	Request for Transfer of Control	G.I. Message/ATC Mail	L/H
4.7.8 - Subtask - Determine That Aircraft Is Leaving Sector	R/A	Geographic Map Data, Target Position Symbol	Situation Display	H/H
4.7.9 - Subtask - Detect Manual Handoff Mode Indication	R	Handoff Alert Indication, Auto Handoff Inhibited	Full Data Block	L/M
4.7.10 - Subtask - Request Transfer Of Flight Data Plan To Another Facility	E	N/A	N/A	L/M
4.7.11 - Subtask - Inform Controller Of Any Conditions Affecting Transfer Of Control	E/VC	N/A	N/A	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.7.12 - Subtask - Inform Controller Of Relinquished Control Of Aircraft	E/VC	N/A	N/A	M/H
4.7.13 - Subtask - Detect Handoff Alert Indication	R	Handoff Alert Indication, Handoff Not Accepted	Full Data Block	L/H
4.7.14 - Subtask - Redirect Handoff	E	N/A	N/A	L/H
4.7.15 - Subtask - Receive Handoff Rejection	R/VC	Handoff Status/ Indicator	Full Data Block	L/E
4.8 - TASK - Issuing Pointouts				
4.8.1 - Subtask - Initiate Pointout	E/VC	N/A	Full Data Block	L/H
4.8.2 - Subtask - Force Flight Data Entry To Another Controller	E	N/A	N/A	L/M
4.8.3 - Subtask - Receive Acceptance Of Pointout	R/VC	Pointout Indicator Accept	Full Data Block	M/H
4.8.4 - Subtask - Receive Rejection Of Pointout	R/VC	Pointout Indicator Reject	Full Data Block	L/H
4.8.5 - Subtask - Discuss Pointout With Other Controller	VC	N/A	N/A	L/H
4.9 - TASK - Responding To Pointouts				
4.9.1 - Subtask - Receive Pointout	R/VC	Full Data Block	Situation Display	M/H
4.9.2 - Subtask - Accept Pointout	E/VC	N/A	N/A	M/H
4.9.3 - Subtask - Deny Pointout	E/VC	N/A	N/A	L/H
4.9.4 - Subtask - Suppress Full Data Block After Pointout	E	N/A	N/A	L/L
4.9.5 - Subtask - Determine Response To Pointout	R/A	Data Block, Flight Data Entry, Geographic Map Display	Situation Display, Flight Data Display	M/H
4.10 - TASK - Issuing Clearances				
4.10.1 - Subtask - Approve Clearance Request	VC	N/A	N/A	H/H
4.10.2 - Subtask - Suggest Clearance Alternatives To Pilot	VC	N/A	N/A	M/M
4.10.3 - Subtask - Formulate A Clearance With Appropriate Instructions	A	N/A	N/A	H/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.10.4 - Subtask - Issue Clearance And Instructions To Pilot	VC	N/A	N/A	H/H
4.10.5 - Subtask - Issue Clearance Through ATCT/FSS For Relay To Pilot	E/VC	N/A	N/A	L/H
4.10.6 - Subtask - Verify Aircraft Compliance With Clearance	R/A	Target Position Symbol, Full Data Block, Position History	Situation Display	H/H
4.10.7 - Subtask - Query Pilot Regarding Conformance With Clearance	VC	N/A	N/A	L/H
4.10.8 - Subtask - Deny Clearance Request	E/VC	N/A	N/A	L/M
4.10.9 - Subtask - Suggest Alternative To Clearance Request From Controller	E/VC	N/A	N/A	L/M
4.11 - TASK - Managing Automated Handoff Features				
4.11.1 - Subtask - Inhibit Automatic Handoff For All Tracks Or For Designated Track	E	N/A	N/A	L/L
4.11.2 - Subtask - Restore Automatic Handoff For All Tracks Or For Designated Track	E	N/A	N/A	L/L
4.12 - TASK - Establishing, Maintaining, And Terminating Radio Communications				
4.12.1 - Subtask - Receive Request To Cancel Air Traffic Services	VC	N/A	N/A	L/L
4.12.2 - Subtask - Terminate Radio Communications With Aircraft	VC	N/A	N/A	L/L
4.12.3 - Subtask - Receive Arrival Message	VC	N/A	N/A	L/M
4.12.4 - Subtask - Determine Frequency In Use By Receiving Sector	R/A	Radio Frequency, Communication Status, Sector Frequency	System Status Information, Communications A/G Display, Static Information Display	L/M
4.12.5 - Subtask - Issue Change Of Frequency To Pilot	VC	N/A	N/A	H/M
4.12.6 - Subtask - Receive Inital Radio Contact From Pilot	VC	N/A	N/A	H/H
4.12.7 - Subtask - Issue Altimeter Setting	R/VC	Altimeter Setting	A&M Data Display	H/M
4.12.8 - Subtask - Verify Aircraft Altitude	R/A/VC	Full Data Block, Flight Data Entry	Situation Display, Flight Data Display	H/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
4.13 - TASK - Establishing/ Reestablishing Radar Indentification				
4.13.1 - Subtask - Observe Target Entering Radar Coverage	R/A	Target Symbol, Full Data Block, Limited Dta Block	Situation Display	H/M
4.13.2 - Subtask - Inform Pilot That Radar Contact Is Established	VC	N/A	N/A	H/M
4.13.3 - Subtask - Conduct Radar Indentification Procedures	VC/R	Target Position Symbol, Background Descriptor, Data Block	Situation Display	M/H
5.0 - ACTIVITY - Assess Weather Impact				
5.1 - TASK - Responding To Significant Weather Information				
5.1.1 - Subtask - Detect A&M Alert	R	Hazardous Weather Alert, A&M Alert	Situation Display, A&M Data Display	L/H
5.1.2 - Subtask - Receive Weather Briefing From Meteorologist	R/VC	Weather Briefing	G.I. Message/ATC Mail	L/H
5.1.3 - Subtask - Determine Whether Another Controller Or Pilot Needs Weather Advisory	A	N/A	N/A	L/H
5.1.4 - Subtask - Receive PIREP On Weather	R/VC	PIREP	A&M Display	L/M
5.1.5 - Subtask - Issue Weather/ Advisory/Update To Pilot/Another Controller	E/VC	N/A	N/A	L/H
5.1.6 - Subtask - Inform Supervisor/ TMC Of Weather Impact On Routes/ Flow	E/VC	N/A	N/A	L/H
5.1.7 - Subtask - Request Weather Information	E/VC	N/A	N/A	L/M
5.1.8 - Subtask - Receive Weather Advisorsy From Another Controller/ Supervisor/Meteorologist	R/VC	Weather Advisory	G.I. Message/ATC Mail	L/H
5.1.9 - Subtask - Receive Controller Request For Weather Information	R/VC	Request Weather Information	G.I. Message/ATC Mail	L/M
5.1.10 - Subtask - Forward Weather Information To Supervisor/Meteorologist	E/VC	N/A	N/A	L/M
5.1.11 - Subtask - Broadcast Recorded Weather Information	VC	N/A	N/A	L/M

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
5.1.12 - Subtask - Request Supervisor/ TMC To Release Airspace	E/VC	N/A	N/A	L/L
5.1.13 - Subtask - Acknowledge A&M Alert	E	N/A	N/A	L/L
5.1.14 - Subtask - Observe Display Of Weather Line/Intensity/ Movement	R/A	Graphic ATC Weather	Situation Display	L/H
5.1.15 - Subtask - Determine Weather Impact On Routes/ Flow	A	N/A	N/A	L/H
5.1.16 - Subtask - Dtermine Altitude/ Route Change To Bypass Severe Weather	A	N/A	N/A	L/H
5.1.17 - Subtask - Evaluate Impact Of New A&M Condition	R/A	A&M	A&M Data Display	L/M
5.1.18 - Subtask - Receive New Routing For Weather Avoidance From Supervisor/TMC	R/VC	Usage of Adapted Routes, Traffic Management Information, Flight Data Display	Special Lists, System Status Information, Flight Data Display, G.I. Message/ATC Mail, TFC Management Information	L/H
6.2.1 - Subtask - Verify That All Required Parameters Are In Proper Location	R/A	Parameter Settings	Logical Displays, Physical Console Settings	L/M
6.2.2 - Subtask - Sign Of At Designated Console	E	N/A	N/A	L/L
6.2.3 - Subtask - Adjust Workstation To Personal Preference	E	N/A	N/A	L/L
6.2.4 - Subtask - Check Workstation For Proper Configuration, Usability, And Satisfactory Status	R/A	Display Configuration, Usability, Status	Logical Displays	M/M
6.2.5 - Subtask - Set Up Workstation Adaptation Parameters	E	N/A	N/A	L/L
6.2.6 - Subtask - Review Briefing Checklist/Notes To Assure Completeness Of Briefing Coverage	E/R/A/VC	Position Checklist, Free-form Text Item	Static Information Display, Controller Notepad Display	L/M
6.2.7 - Subtask - Request Implementation Of Programmed Personal Preference Adjustments	E	N/A	N/A	L/L
6.2.8 - Subtask - Dtermine If Ready To Accept Control Responsibility	A	N/A	N/A	L/H
6.2.9 - Subtask - Review Current And Projected Traffic Status/Weather	R/A	Traffic, Flight Data, Weather, Traffic Management Information	All Logical Displays	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
6.2.10 - Subtask - Review System Status To Determine Currency/Update Self	R/A	System Status Information, Position Checklist	System Status Information, Special Lists, Static Information Display	L/M
6.3 - TASK - Responding To Transient Computer Failures				
6.3.1 - Subtask - Detect Non-Acceptance Of Input Data	R/A	Operational Function Degradation/Failure, Data Reject Message	All Logical Displays on whic Data can be Input, Computer Outage	L/H
6.3.2 - Subtask - Routing	R/VC	Traffic Management Information, Substitute Routing	Special Lists, G.I. Message/ATC Mail	L/M
6.6.4 - Subtask - Receive Cancellation Of Substitute Routing	R/VC	Traffic Management Information, Cancel Substitute Routing	Special Lists, G.I. Message/ATC Mail	L/M
6.6.5 - Subtask - Forward Navaid Status To Another Controller/Supervisor/ Pilot	E/VC	N/A	N/A	L/M
6.6.6 - Subtask - Discuss Appropriateness With Supervisor Of Releasing Equipment To Maintenance	A/VC	N/A	N/A	L/L
6.6.7 - Subtask - Review Need/ Cancellation Of Substitute Routing With Supervisor	A/VC	N/A	N/A	L/L
6.6.8 - Subtask - Receive Supervisor Notice Of Equipment Release To Maintenance	R/VC	Equipment Released to Maintenance	G.I. Message/ATC Mail	L/M
6.6.9 - Subtask - Review Status Of Questionable Navaid	R/VC	Navaid Outage, Navaid Repair Schedule	System Status Information	L/L
6.6.10 - Subtask - Observe Substitute Routing On Display	R	Substitute Routing, Usage of Adapted Routes	Static Information Display, Sytem Status Information	L/L
6.6.11 - Subtask - Forward Substitute Routing	E/VC	N/A	N/A	L/H
6.6.12 - Subtask - Delete Previous Substitute Routing	E/VC	N/A	N/A	L/M
6.7 - TASK - Executing Backup Procedures For Communication Failures				
6.7.1 - Subtask - Detect Communication Failure	VC/A	N/A	N/A	L/H
6.7.2 - Subtask - Forward Alternative Communication Path	E/VC	N/A	N/A	L/H
6.7.3 - Subtask - Receive New Frequency Assignment	R/VC	New Frequency	G.I. Message/ATC Mail	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
6.7.4 - Subtask - Forward Notice Of Communication Status	E/VC	N/A	N/A	L/M
6.7.5 - Subtask - Forward New Frequency Assignment To Another Controller/ Supervisor/Pilot	E/VC	N/A	N/A	L/H
6.7.6 - Subtask - Receive Notice Of Alternative Communication Path	R/VC	Alternative Communication Path	G.I. Message/ATC Mail	L/H
6.8 - TASK - Managing Personal Workload				
6.8.1 - Subtask - Determine Impending Controller Overload	A	N/A	N/A	L/H
6.8.2 - Subtask - Request Assistance Or Relief	E/VC	N/A	N/A	L/H
6.8.3 - Subtask - Request Flow Control Be Imposed	E/VC	N/A	N/A	L/H
6.9 - TASK - Performing Procedures For Non-Radar Environment				
6.9.1 - Subtask - Inform Pilot Of Radar Contact Lost	VC	N/A	N/A	L/M
6.9.2 - Subtask - Reassociate Data Block	E	N/A	N/A	L/M
6.9.3 - Subtask - Observe Data Block Not Associated With Target	R	Data Block, Target Position Symbol	Situation Display	L/M
6.9.4 - Subtask - Terminate Radar Service To Aircraft	VC	N/A	N/A	L/M
6.9.5 - Subtask - Initiate Use Of Non-Radar Separation Standards	R/A	Data Block, Target Position Symbol	Flight Data Display, Situation Display	L/M
6.9.6 - Subtask - Initiate Use Of Radar Separation Standards	R/A	Full Data Block, Target Position Symbol	Situation Display	L/M
6.9.7 - Subtask - Request Pilot Position Reports	VC	N/A	N/A	L/H
6.9.8 - Subtask - Observe Return To Normal Radar Environment	R/A	Full Data Block, Target Position Symbol	Situation Display	L/H
6.9.9 - Subtask - Observe Aircraft In Track Coast Mode	R	Coast Indicator, Track Status	Track Position Symbol, Full Data Block	L/H
6.10 - TASK - Executing Backup Procedures For Loss Of Flight Plan Data Base				

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
6.10.1 - Subtask - Observe Message On Loss Of Flight Plan Data Base	R	Operational Function Degradation/Failure, Computer Outage	System Status Information	L/H
6.10.2 - Subtask - Detect Failure To Update Flight Plan Data Base	R/A	Flight Plan Data Base Not Updating	Flight Data Display	L/H
6.10.3 - Subtask - Enter Display Amendment Message On Console	E	N/A	N/A	L/H
6.10.4 - Subtask - Enter Flight Plan On Console	E	N/A	N/A	L/H
6.10.5 - Subtask - Verify Flight Plan Data Base Transition Activities	E/R/VC	Flight Data Entry, Full Data Block, Transition Verification	Flight Data Display, Situation Display, G.I. Message/ATC Mail	L/M
6.11 - TASK - Responding To Transient Communications Failures				
6.11.1 - Subtask - Detect Unreliable Radio Communication	A/VC	Unreliable Radio Communication	Direct Observation	L/H
6.11.2 - Subtask - Query Whether Others Are Receiving An Aircraft's Transmissions	E/VC	N/A	N/A	L/H
6.11.3 - Subtask - Issue Alternative Communication For Air/Ground Transmission	VC	N/A	N/A	L/H
6.11.4 - Subtask - Receive Notice of Transient Communication Failure	R/VC	Transient Communication Failure	G.I. Message/ATC Mail	L/M
6.12 - TASK - Responding To Airspace Reconfigurations/ Resectorizations				
6.12.1 - Subtask - Receive Notice To Take Over Airspace	R/VC	Take over Airspace	G.I. Message/ATC Mail	L/H
6.12.2 - Subtask - Receive Notice To Release Airspace	R/VC	Release Airspace	G.I. Message/ATC Mail	L/H
6.12.3 - Subtask - Receive Notice That Adjacent Facility Is Inoperative	R/VC	Adjacent Facility Inoperative	G.I. Message/ATC Mail	L/H
6.12.4 - Subtask - Receive Notice To Prepare For Sector Reconfiguration	R/VC	Notice to Prepare for Reconfiguration	G.I. Message/ATC Mail	L/H
6.13 - TASK - Responding To Sensor Outages				
6.13.1 - Subtask - Receive Notice Of Radar Sensor Status	R/VC	Radar Equipment Outage	G.I. Message/ATC Mail	L/H

TABLE 2: ATC Task Requirements Matrix (Con't)

Task Statement	Task Type	Information Received	Information Source	Freq/Crit
6.13.2 - Subtask - Receive Procedures To Be Used To Accommodate Sensor Outage	R/VC	Sensor Outage Procedures	G.I. Message/ATC Mail	L/H
6.13.3 - Subtask - Perceive Tracking Or Transponder Failure	R/A	Track Swap, False Return, Track Disassociation, Coast Indicator, Transponder Failure Notice	Situation Display, Full Data Block, Position Symbol	L/H
6.13.4 - Subtask - Forward Notice Of Radar Sensor Status To Another Controller/ Supervisor	E/VC	N/A	N/A	L/M

APPENDIX D
EXTRACTED FROM CAATS OPERATIONAL PERFORMANCE REQUIREMENTS, TRANSPORT CANADA PUBLICATION TP 9166E

GROUPS & COMPONENTS	CCWS (S)	CCWS (T)	OSS WS	DSC WS	FM WS	CT WS	IIOT	ARU WS
AERONAUTICAL								
Information (Section 2.1.10)		X	X	X	X	X		X
Static Aircraft Reg. Data		X	X	X	X	X		
Dynamic Altimeter Data	X	X		X				
METEOROLOGICAL DATA								
As contained in Section 2.1.4		X	X	X	X	X		
UNIT LIBRARY INFORMATION		X	X	X	X	X		X
SYSTEM DATA								
Alert Messages	X	X	X	X	X	X	X	X
Warning Messages	X	X	X	X	X	X	X	X
Error Messages	X	X	X	X	X	X	X	X
System Messages	X	X	X	X	X	X	X	X
Sectorization		X	X	X	X	X	X	
Prompts	X	X	X	X	X	X	X	X
Help	X	X	X	X	X	X	X	X
RDPS DATA								
FDB	X			X				
CJS	X			X				
Special Conditions	X			X				
RDPS Alerts	X			X				
RDPS Met. Areas	X			X				
MAP DATA								
Situation Display Maps	X			X	X			X
Secondary Maps	X	X	X	X	X			X
AIRSPACE DATA								
Special Use Airspace	X	X		X	X			X

DISPLAY REQUIREMENTS (Cont.)

TABLE 2.12-1

GROUPS & COMPONENTS	CCWS (S)	CCWS (T)	OSS WS	DSC WS	FM WS	CT WS	IIOT	ARU WS
SPECIAL LISTS								
Selected Weather Elements	X	X	X	X	X	X		X
System Time	X	X	X	X	X	X		X
Hold List	X	X		X		X		
Inbound List	X	X		X	X	X		
Departure List	X	X		X	X	X		
Arrival List	X	X		X	X	X		
OTS Data (NAT)		X	X	X		X		
FLIGHT DATA								
Alerts								
Detect Conflict	X	X		X				X
Conflict Alert Data	X	X		X				X
Resolution Data	X	X		X				X
Flight Profiles	X			X				X
Request Clearance Messages		X		X				
Aircraft Position Reports	X	X		X			X	
Query Reply		X	X	X	X	X	X	X
Flight Plan Display		X	X	X	X	X	X	X
Route Data		X	X	X	X	X	X	X
Eligible AMIS Flights		X	X	X	X		X	
Supplementary Flight Plan Data		X	X	X	X	X	X	
Flight Position		X	X	X	X	X	X	X
Estimates		X		X	X	X	X	X
Revisions		X		X	X	X	X	X
Home Base Data				X		X		
Search & Rescue Data		X	X	X	X	X	X	
ADCUS Messages			X	X			X	
ATC MAIL								
Mail Messages		X	X	X	X	X	X	X
SVC & GI Messages		X	X	X	X	X	X	X
FLOW MANAGEMENT								
Aircraft Delay Data		X		X	X			
Demand List				X	X			
Acceptance Rate				X	X			
Slot Allocation Table		X		X	X	X		
Airspace Loading Level		X		X	X	X		

DISPLAY REQUIREMENTS (Cont.)

TABLE 2.12-1

GROUPS & COMPONENTS	CCWS (S)	CCWS (T)	OSS WS	DSC WS	FM WS	CT WS	IIOT	ARU WS
FLOW MANAGEMENT (Cont.)								
Sector Loading Level		X		X	X			
System-Stored Tables		X		X	X			
AIRPORT DATA								
Runway-In-Use				X	X	X	X	
Specific Airport A&M Data		X	X	X	X	X		
PROCESS CONTROL DATA DISPLAY								
Equipment Configuration Data				X				X
Recording Control Data				X				X
Sector Configuration Data				X				
System Performance Data				X				X
Parameter Data				X				X

N.B. Additional control tower requirements for display are identified in Section 3.0.

DISPLAY REQUIREMENTS (Cont.)

TABLE 2.12-1